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FEASIBILITY OF RAMJET ENGINE TEST CAPABILITY ON THE HOLLOMAN SLED TRACK

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L. E. McTaggart

THE MARQUARDT COMPANY

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AIR FORCE AERO PROPULSION LABORATORY

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

The research reported herein was conducted for the Air Force Aero Propulsion Laboratory, Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio, Lt. Jerry Ross (AFAPL/RJA-1), Project Engineer. This investigation was a joint venture between the 6585 Test Group/TK and the Air Force Aero Propulsion Laboratory. The Marquardt Company's contribution was accomplished under USAF Contract F33615-71-C-1372 over the period May 1971 through April 1973. The contract was initiated under Project 3012, "Ramjet Technology" Task 301201, "Ramjet Component Integration." This program was initiated with FY'71 Air Force Aero Propulsion Laboratory Director's Funds.

This report which presents the detail of the SCP/LASRM flight hardware modifcations and combustion test results on the Holloman AFB High Speed Sled Track was prepared as Marquardt Report S-1267 and submitted on 25 July 1973.

Recognition is given to the contributions made by all the associated contractor and Air Force Personnel in the successful completion of this feasibility study. Marquardt's design and modifications to the SCP/LASRM hardware and combustion performance analyses was complementary to North American Rockwell, Columbus Divisions sled modifications and dynamics analysis. These were, in turn, complementary to the 6585 Test Group/TK Track Operations and the University of New Mexico's load cell design.

Publication of this report does not constitute Air Force Approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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AD-769043

ABSTRACT

Under a joint program between the 6585 Test Group/TK and the Ramjet and Laser Aerodynamics Division of the Air Force Aero Propulsion Laboratory, an existing monorail test sled is modified to accept the SCP/LASRM test vehicle. The necessary structural modifications are made to the SCP/LASRM hardware to withstand the applied loads imposed by the sled.

The feasibility of ramjet engine test capability on the Holloman Sled Track is confirmed by comparison of ramjet performance data obtained during high speed sled tests to that available from previous ground freejet and flight tests with this engine. Propulsion performance data over the Mach range 2.3 to 2.5 at zero degree angle of attack were obtained from the sled tests.

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SECTION I

INTRODUCTION

The capability of obtaining realistic test data on low altitude airbreathing propulsion systems when utilizing the rocket sled track facility has been considered for a number of years. However, the capability of the sled track to provide airbreathing propulsion system data has never been demonstrated. In order to answer the questions concerning the sled track's airbreathing propulsion test capability, a joint program between the 6585 Test Group/TK and the Air Force Aero Propulsion Laboratory was undertaken.

Under this joint program, an existing monorail test sled was modified to accept the SCP/LASRM test vehicle. The necessary structural modifications were made to the SCP/LASRM hardware to withstand the applied loads imposed by the sled. Structural adequacy and velocity profile were determined during an initial series of four cold flow (no ramjet combustion) tests. Ramjet performance was then demonstrated during two hot flow (ramjet combustion) tests.

Under this joint program, the 6585 Test Group/TK was responsible for providing the analytical effort to develop math models of sled and test article structural behavior, designing and modifying an existing sled and conducting the sled test. The Air Force Aero Propulsion Laboratory was responsible for providing applicable SCP/LASRM residual hardware, the design and modification of the mid-section of the LASRM test vehicle, engineering support of Holloman's sled contractor(s), the fuel system, test support and data evaluation. The Marquardt was under contract to the Air Force Aero Propulsion Laboratory to provide these services (AF Contract F33615-71-C-1372).

The 6585 Test Group/TK engaged North American Rockwell, Columbus Division (NAR-C) to provide the analytical effort to develop math models of the sled and test article structural behavior. In addition, NAR-C modified an existing monorail test sled and verified the math model against vibration data obtained during the initial cold flow structural tests.

The University of New Mexico was engaged by the 6585 Test Group to provide the design, fabrication, and instrumentation of load cells with which the loads applied to the test article by the sled will be determined.

The 6585 Test Group was responsible for supplying the test sled, the telemetry and the residual rocket motors for use as booster and sustainer. The 6585 Test Group was also responsible for the conduct of a ground vibration test (GVT) on the assembled sled and test article as well as conduct of both the cold flow structural tests and ramjet performance tests.

The feasibility of ramjet engine test capability on the Holloman Sled Track was confirmed by comparison of ramjet performance data to that available from previous tests with this engine. Extensive testing was accomplished with the SCP/LASRM Flight Test Program (Contract F33(615)14295). Data are available from wind tunnel inlet model tests, engine free jet tests, combustor tests, and flight tests. Typical inlet performance and combustion performance data are shown in Figure 1.

Primary performance evaluated is that of the inlet and the combustor. Inlet performance is defined by pressure recovery data obtained during tests on two inlets that are instrumented. Combustion performance is defined by the combustion chamber pressure data, air flow, and fuel flow.

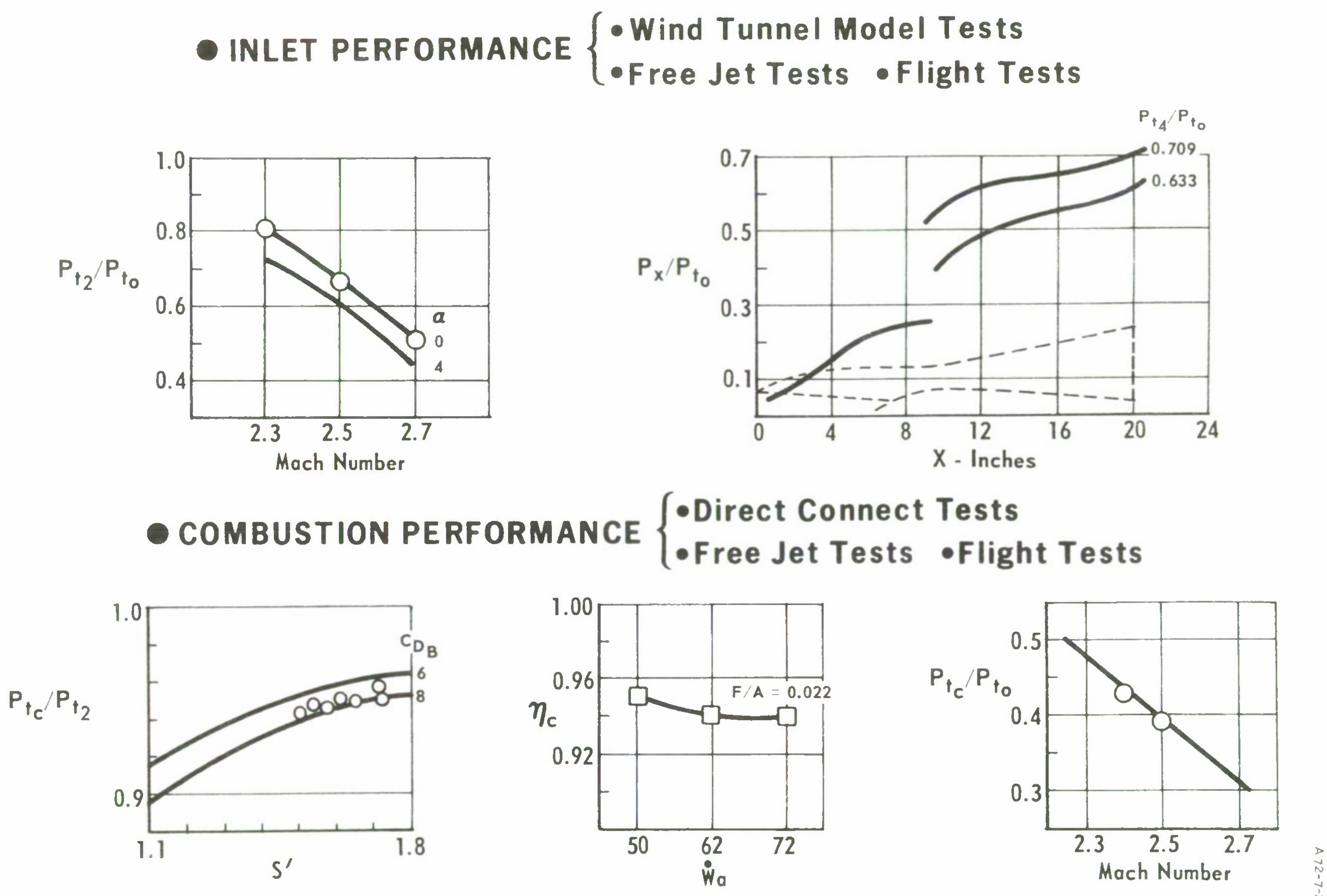


Figure 1. SCP/LASRM Performance Background.

SECTION II

SUMMARY

The capability of obtaining realistic test data on low altitude airbreathing propulsion systems when utilizing the rocket sled track facility has been demonstrated. Under a joint program, the 6585 Test Group/TK and the Aero Propulsion Laboratory successfully tested the SCP/LASRM flight engine on a modified monorail sled with outrigger. Propulsion performance data were obtained over the Mach range 2.3 to 2.5 at zero degree angle of attack.

The FRT hardware from the SCP/LASRM Flight Demonstration Program (F33(615)14295) was structurally upgraded to withstand the dynamic load input of the rocket boosted sled. Structural modification and interfacing to the test sled were designed so as to preserve the aerodynamic similarity with the ground freejet test hardware, the wind tunnel model, and the flight test hardware. The structural changes made to the propulsion test hardware are summarized as:

(1) The LASRM fuel tank which serves as a portion of the missile structure has a nominal wall thickness of 0.050 inch. This section was replaced with a 15-inch diameter rolled ring section with a nominal thickness of 0.12 inch. The intersection at Station 95.125 to the forebody is a weld joint.

(2) The LASRM mid-section has four large cutouts for installation of the inlets. A doubler plate with a nominal thickness of 0.12 inch was added between each pair of inlets to provide sufficient strength to withstand the predicted bending moments through this section.

(3) The divergent section of the flight engine exit nozzle was removed to save weight and to eliminate a potential structural problem. Combustion performance was determined by chamber pressure (P4) and the removal of the divergent section does not affect this measurement.

(4) Primary change was at Station 124.4 where the forward support mount loads are reacted. A bolted flange joint was used to replace the submerged joint of the flight engine. The flanged joint connects the mid-section to the combustion section and serves as the primary interface to the sled support mount.

The primary structural design requirement is at Station 124.4 where the forward support mount is located. Significant modification to the LASRM structural joint in this location was made to provide a positive margin of safety. The reactive loads to which the forward support was designed are summarized as:

Axial	14,030 lbs
Vertical	87,440 lbs
Lateral	42,500 lbs
Rolling Moment	287,000 in-lbs

The forward mount ring, support legs, and base were formed from a single piece forging of 4340 steel heat treated (1700°F) to 160 Ksi. The mount ring was attached to the test item through twenty four 1/2-inch diameter bolts and interfaced to the test sled through a load cell which utilized sixteen 3/8" bolts and four 1/4" shear pins.

The design of the forward mount incorporated several features: (1) low drag profile, (2) high load carrying capability for its total mass, (3) open areas to maintain an aerodynamically clean flow field, (4) shear loads taken out through shear pins thus eliminating the need for close tolerances at the load cell interface.

The loads at the aft support was taken out through a 1/8 inch thick flexure plate which interface with the sled through a 2-3/4" x 10" x 3-1/2" load cell. The magnitude of the loads to be reacted permitted a simplified light weight design to be adapted. The reactive loads are:

Veritcal	57,200 lbs
Lateral	23,100 lbs.

A palletized fuel supply and flow control system was located in the test sled just aft of the forward support mount. Criteria for the fuel system required the system to be totally contained in the sled within a volume of 14" x 18" x 12". With the exception of the fuel tank, the same components were used as were used in the LASRM fuel control. The nitrogen pressured fuel tank has a fuel capacity of 1.7 gallons. The nominal fuel flow rate was 1.1 pounds per second which provided approximately 12 seconds fuel flow.

The ignition system is the same unit used in the SCP/LASRM flight demonstration program. A pyrophoric material, Tri Ethyl Borane (TEB), was injected into the combustion chamber in the region of the fuel injection.

Instrumentation of two inlets, the combustion chamber and fuel supply pressure was provided to permit determination of inlet, combustor, and fuel system performance during a test run.

The test program was conducted in two phases: (1) cold flow (non-combustion) structural tests and (2) ramjet performance tests. During the four cold flow tests, no propulsion data were scheduled; however, the dynamic loads data and mathematical model were confirmed by North American-Columbus. A checkout of the fuel supply system and cold flow inlet performance was obtained during the fourth cold flow run. No attempt was made to ignite the flowing fuel. Maximum velocity on this run was 2821 fps with 3.8 seconds of time above Mach 2.3. A spot check of the P_X/P_{T_O} static pressure ratios showed that the inlets started and operated satisfactorily.

An electrical malfunction in the Conax squib valve prevented the TEB igniter from operating on the first scheduled combustion ("hot flow") test. Cold flow inlet data were obtained and compared favorably with available freejet test data.

The second combustion ("hot flow") test was successfully conducted on 6 April 1973. A maximum velocity of 2826 fps was attained with 4.19 seconds above Mach 2.3. Good comparison is obtained for P_{t_4}/P_{t_0} between freejet data and sled data during the decleration portion of the trajectory. An unexplained hysteresis is seen in the data as a function of acceleration vs. deceleration.

Further testing with the sled is scheduled by Air Force Aero Propulsion Laboratory to obtain performance data at a negative 4° angle of attack.

SECTION III

TEST HARDWARE

A schematic of the test assembly is shown in Figure 2 . The payload, a structurally modified SCP/LASRM flight test engine, is mounted on an existing monorail sled with outrigger. The sled was modified to accept the LASRM payload and mounting system. The payload is unchanged aerodynamically from the configurations tested during the SCP/LASRM freejet and flight tests. The vehicle is mounted in a forward position to present an aerodynamically clean flow field to the propulsion air induction system.

Initial acceleration is provided by two pusher sleds containing four (4) MK 7 Mod 0 motors each. As each stage reaches burnout, that pusher sled is detached from the test assembly. A sustainer motor (MK 12 Mod 1) plus two canted nozzle Recruit motors provide the final acceleration and maintains velocity above Mach 2.3 for the desired time interval.

The assembled propulsion system hardware is shown in Figure 3 with the forward and aft mounts installed prior to shipment to North American Rockwell-Columbus for assembly to the test sled.

1. DESIGN CRITERIA

The following design criteria were established to provide guidelines for interfacing the LASRM vehicle to the test sled:

(a) Interference free flow field at the air induction system for velocities above Mach 2.3 and at angles of attack to 4 degrees.

(b) Plane of inlet aft lip to be one inch forward of leading wedge of sled.

(c) Aerodynamic blockage between sled and test item to be sufficiently clean to preclude generation of a normal shock in the vicinity of the inlets.

(d) Mass and drag of the test item and support mounts to be held as low as possible.

(e) Structural design factor to be 1.5 yield and 2.25 to ultimate on bolts.

These are illustrated schematically in Figure 4 .

Interface points between the test sled and the propulsion system payload are established as:

(a) The leading edge of the sled is at Missile (payload) Station 111.400.

(b) The centerline of the forward transducer is at Missile Station 125.525.

(c) The centerline of the aft transducer is at missile station 160.028.

(d) The water line of the top of the forward transducer and bottom of the propulsion interface structure is at W. L. 26.250.

(e) The water line of the top of the aft transducer and bottom of the propulsion interface structure is at W. L. 27.50.

(f) The corners of the forward transducer will have either a minimum of 0.5 inch radius or will be chamfered.

(g) Forebody/Propulsion section interface is Station 95.125.

2. STRUCTURAL DESIGN OF MID-SECTION AND MOUNTS

The magnitude of the loads applied to the test item made it mandatory to structurally upgrade the SCP/LASRM flight hardware. The areas in which the system had to be structurally upgraded are shown in Figure 5 and summarized briefly here:

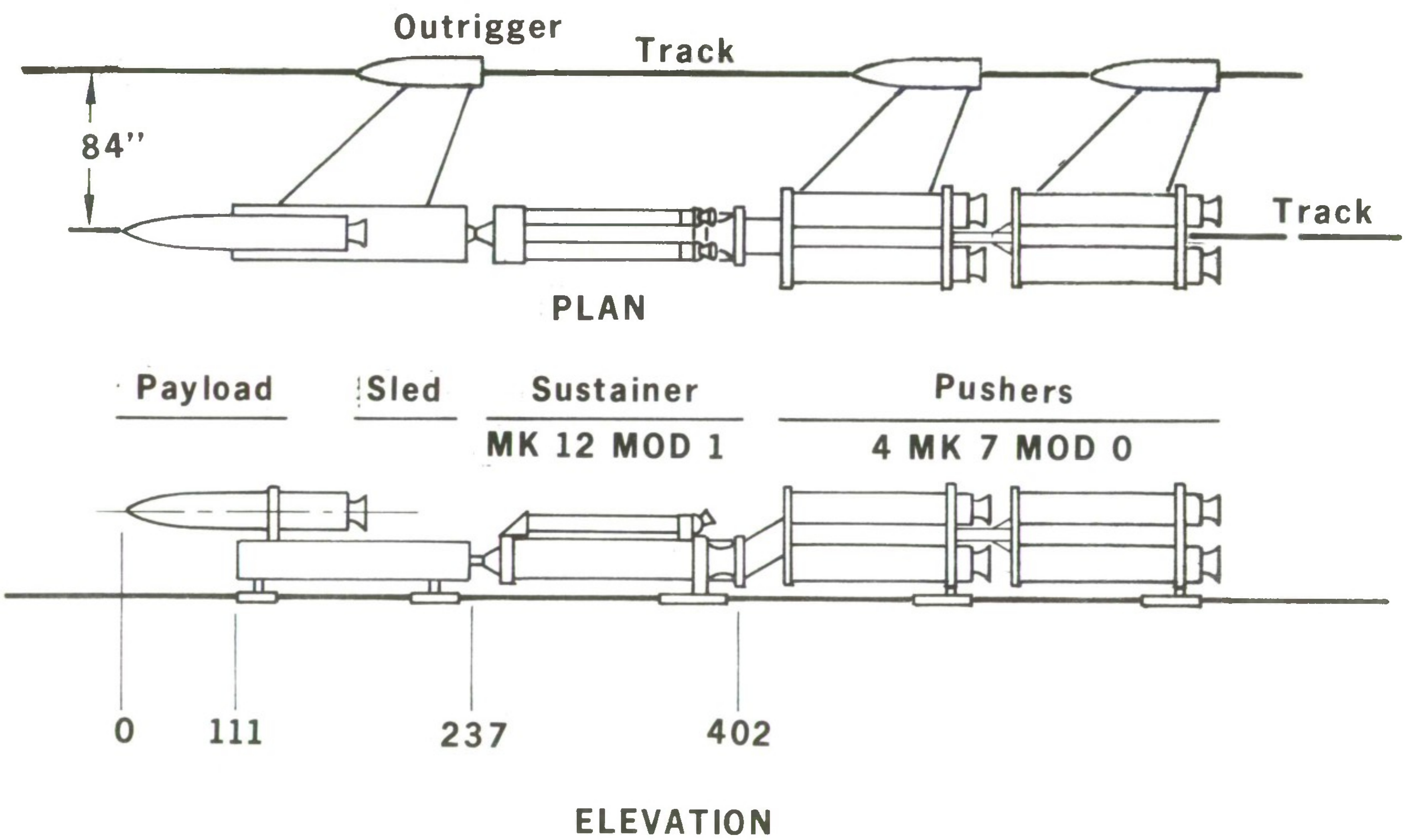
(a) The LASRM fuel tank which serves as a portion of the missile structure had a nominal wall thickness of 0.050 inch. This section was replaced with a 15-inch diameter rolled ring section with a nominal thickness of 0.12 inch. The intersection at Station 95.125 to the forebody is a weld joint.

(b) The LASRM mid-section has four large cutouts for installation of the inlets. A doubler plate with a nominal thickness of 0.12 inch was added between each pair of inlets to provide sufficient strength to withstand the predicted bending moments through this section.

(c) The divergent section of the flight engine exit nozzle was removed to save weight and to eliminate a potential structural problem. Combustion performance was determined by chamber pressure (P_4) and the removal of the divergent section does not affect this measurement.

(d) Primary change was at Station 124.4 where the forward support mount loads are reacted. A bolted flange joint was used to replace the submerged joint of the flight engine. The flanged joint connects the mid-section to the combustion section and serves as the primary interface to the sled support mount.

TEST SLED SCHEMATIC



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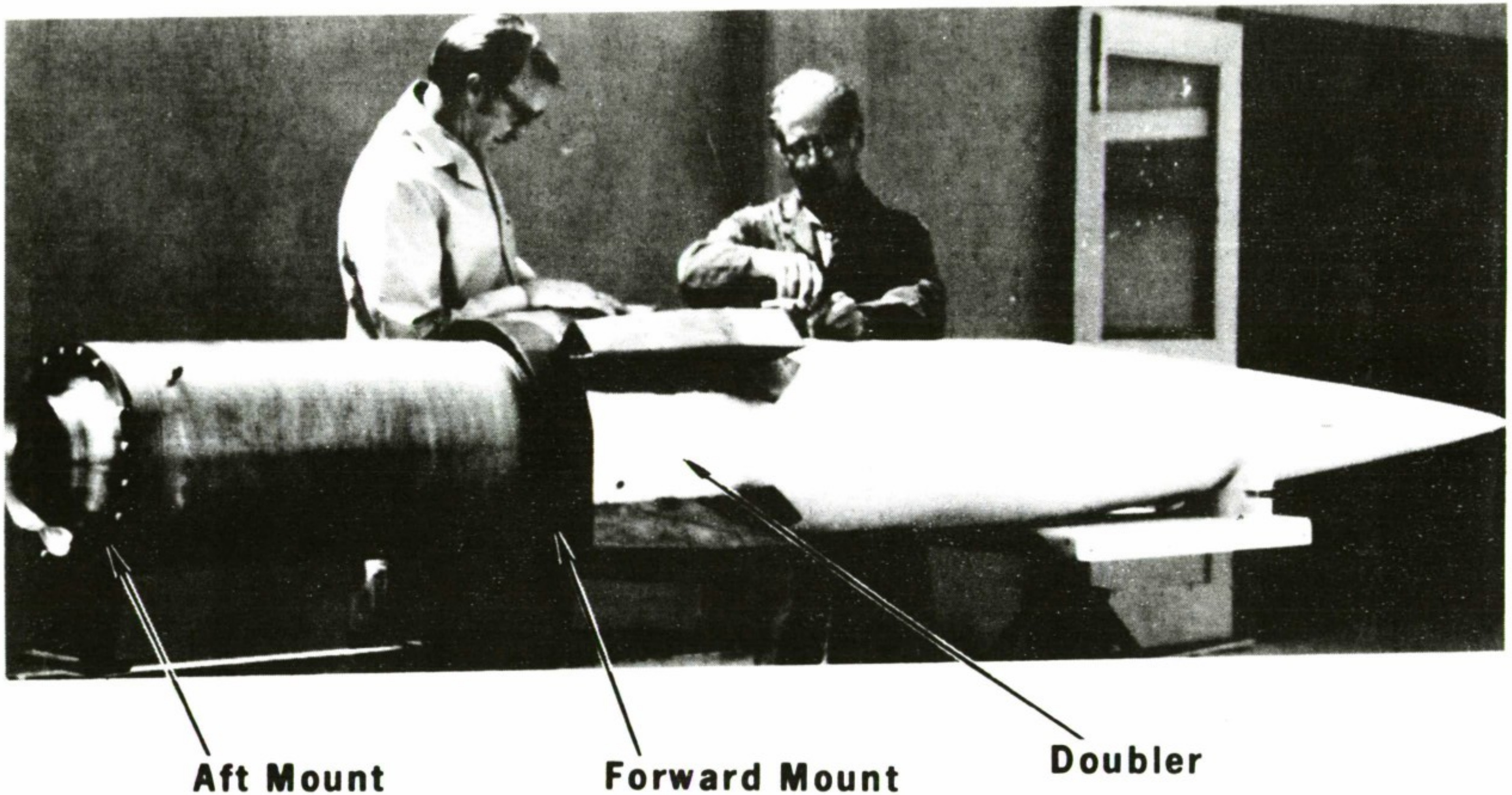

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Figure 3 Modified SCP/LASRM Engine Sled Test

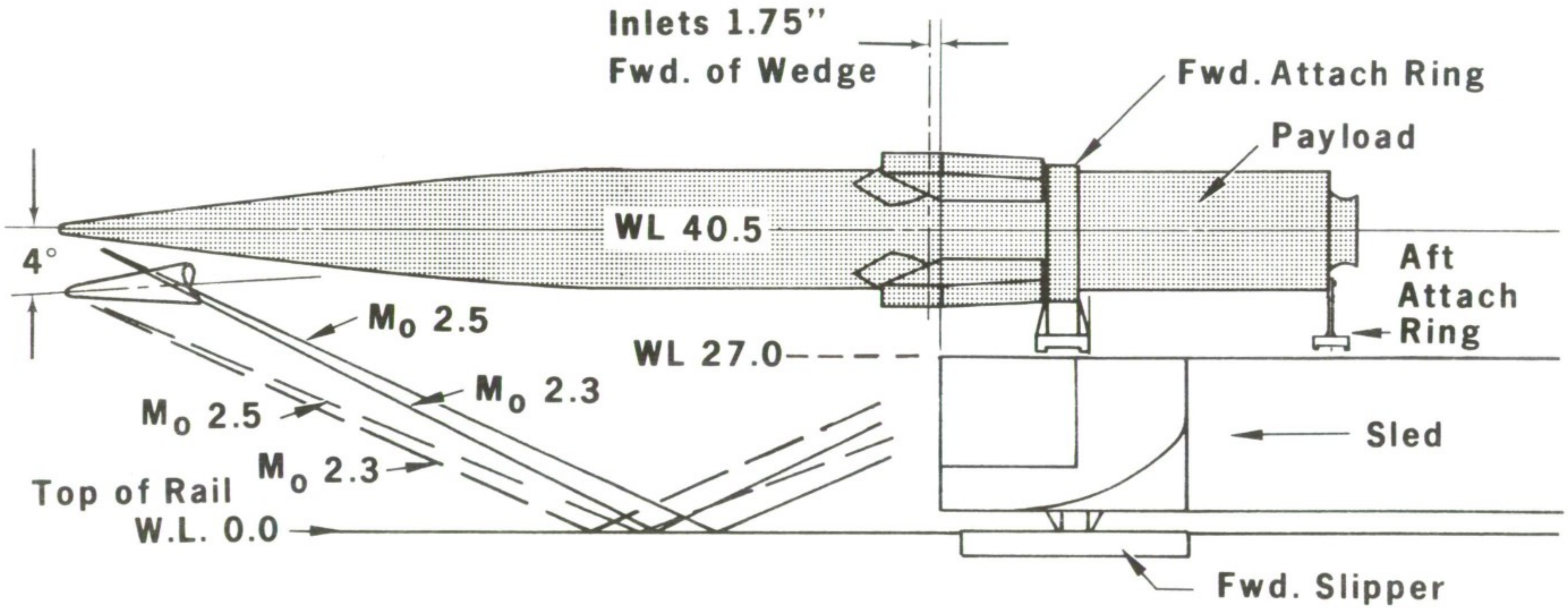
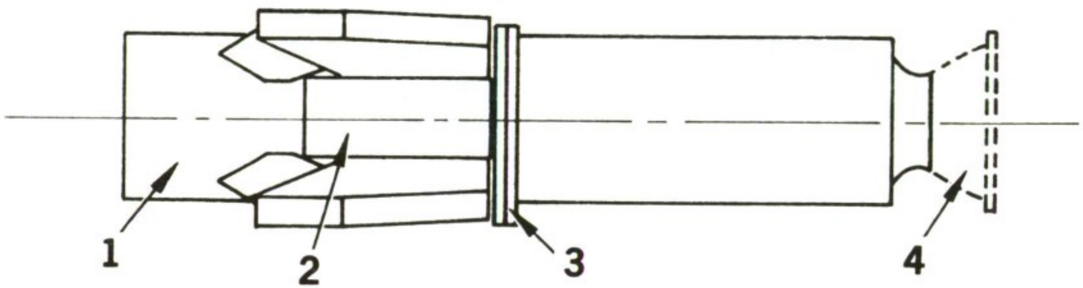


Figure 4. Design Criteria.



1 - Replace Fuel Tank with 4130 Steel Center Section (Sta 95.125 to 109.75) Nominal Thickness 0.12"

2 - Doubler Add 4130 Steel Plate Between Each Inlet (Sta 108.75 to Sta. 122.77) Nominal Thickness 0.12"

3 - Add 4130 Steel Bolt Flanges to Mid Section and Combustion Chamber at Sta. 124.4 Nominal Flange Thickness 1.0". Twenty four (24) .50 Inch Bolts.

4 - Cut Divergent Section from Exit Nozzle One Inch Aft of Throat (Sta. 163)

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Figure 5. Propulsion Hardware Structural Changes.

a. Preliminary Design

Preliminary structural designs for the mid-section, support mount, and the aft support were developed based upon the preliminary loads provided by North American Rockwell-Columbus. These loads, Table I, were presented as representing a rigid sled, flexible load cell, and a flexible payload system.

A schematic of the forward structural mount is shown in Figure 6 . This structure was designed to withstand the loads shown in Table I and to satisfy the aerodynamic criteria for flow area through the mount.

Aerodynamic constraints placed on the Station 124 support structure requires that the projected blockage in the lower quadrant could not be greater than 25 percent of the captured flow area. These areas are designated in Figure 6 as (1) Captured Flow Area and (2) Blockage Area. The aerodynamic constraint was required to assure unchoked flow through the area bounded by the sled, the vehicle body, and the inboard side plates of the lower inlets.

As an input to NAR-C's second iteration to the random loads analysis, the mass properties functions for the propulsion system and structural supports were determined. These are shown in Table II. Stiffness coefficients for the forward support structure are shown in Table III.

It was anticipated that the second iteration to the random loads analysis would reduce the bending moment and shear reactive loads. A modification of the forward support would then be developed directed toward a reduction in the support mass and the frontal drag area. In the following section, the stress analyses for the propulsion system and mounts are based upon the results of this second iteration.

b. Loads and Stress Analysis

The stress analysis for the engine mounts were based upon the loads specified by North American Rockwell-Columbus for the two mounting stations and the payload. The loads are summarized in Tables IV , V , and VI .

The loads are based on the reactions of the payload to the imposed vibration and accelerations from the rocket powered sled and associated track during the test runs. The loads and reactions at the mounting points were all assumed to act simultaneously and during ramjet operation. A bending moment diagram for the test article is shown in Figure 7 . The applied loads are taken as the sum of the quasi-steady state and random loads at a two sigma level. The random component represents an average between the fully correlated and uncorrelated power input.

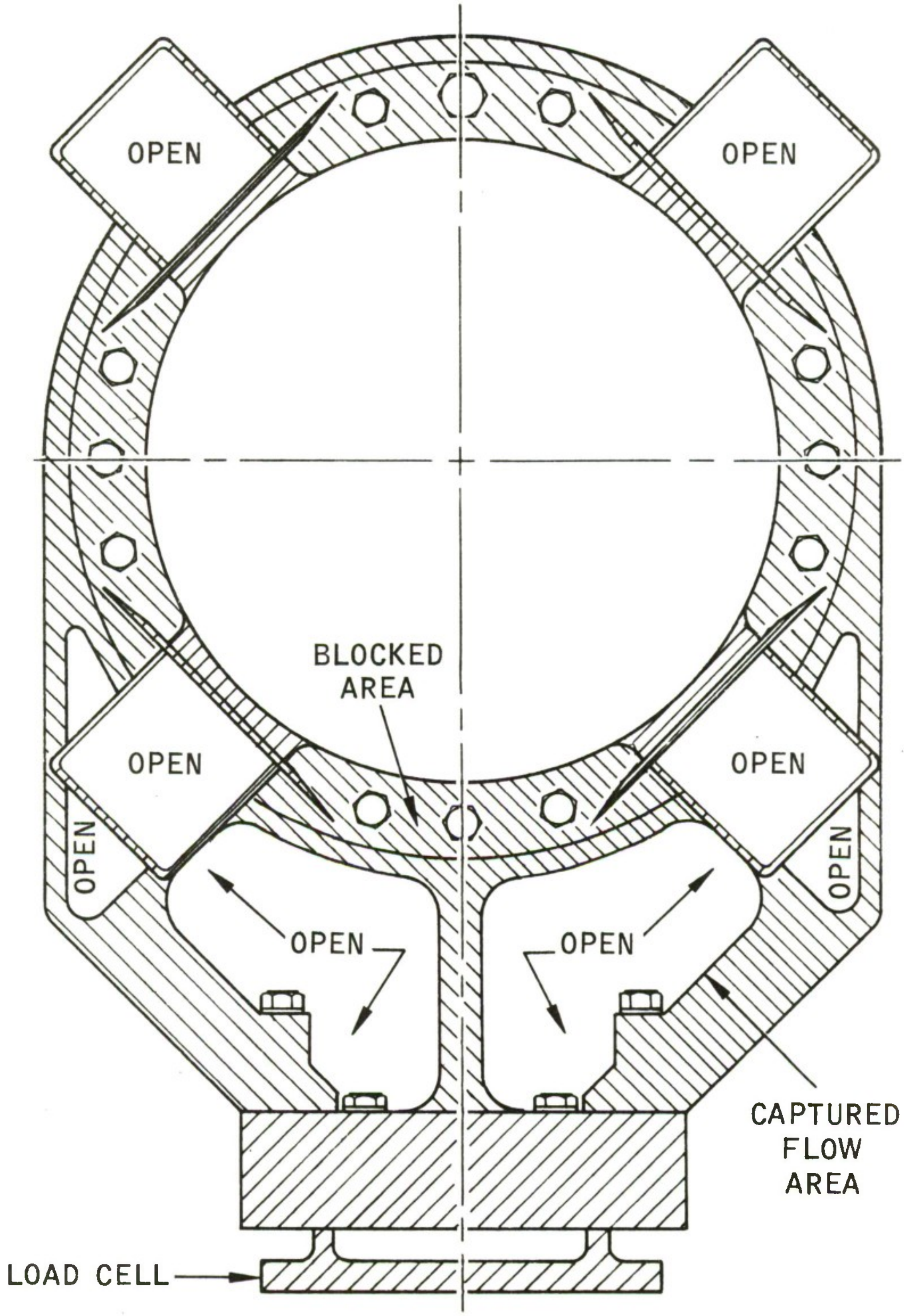


Figure 6. Sta. 124.4 Support Ring and Mount.

TABLE I. REACTIVE LOAD DISTRIBUTION

Missile station	Shear lbs.	Moment in - lbs
90	21,470	1,149,000
100	25,880	1,376,000
110	28,260	1,631,000
120	30,390	1,904,000
124.4	30,400 57,040	2,028,000
130	57,050	1,709,000
140	57,070	1,138,000
150	57,120	566,000
159.9	57,200	0

REACTIVE LOAD SUMMARY

A. Forward Mount

Axial	14,030 lbs
Vertical	87,440 lbs
Lateral	42,500 lbs

B. Aft Mount

Vertical	57,200 lbs
Lateral	23,100 lbs

C. Rolling Moment

287,000 in-lbs (assuming a 12-inch separation between missile and sled)

TABLE II. MASS PROPERTIES TABLE

Section	Weight (LBS.)	$\bar{X}$* (IN.)	$\bar{Y}$* (IN.)	$\bar{Z}$* (IN.)	Roll I_{x-x} lb-in^2	Pitch I_{y-y} lb-in^2	Yaw I_{z-z} lb-in^2
109.250 - 110.0	4.61	109.6	-	-	214.8	106.9	107.4
110.0 120.0	58.55	115.4	-	-	3,520.3	1,760.2	1,760.2
120.0 130.0	349.41	125.1	-	-8.8	29,855.1	23,040.3	14,927.5
130.0 140.0	12.44	135.0	-	-	684.9	342.5	342.5
140.0 150.0	12.44	155.0	-	-	684.9	342.5	342.5
150.0 160.0	49.86	158.4	-	-13.7	4,479.0	3,890.9	2,239.5
160.0 163.250	50.51	160.7	-	10.0	8,415.6	8,206.4	4,207.8
TOTAL	537.85						

*$\bar{X}$ = Longitudinal C.G. from Sta. 0.0 at nose of forebody (inches)

Y & Z = Center line of forebody

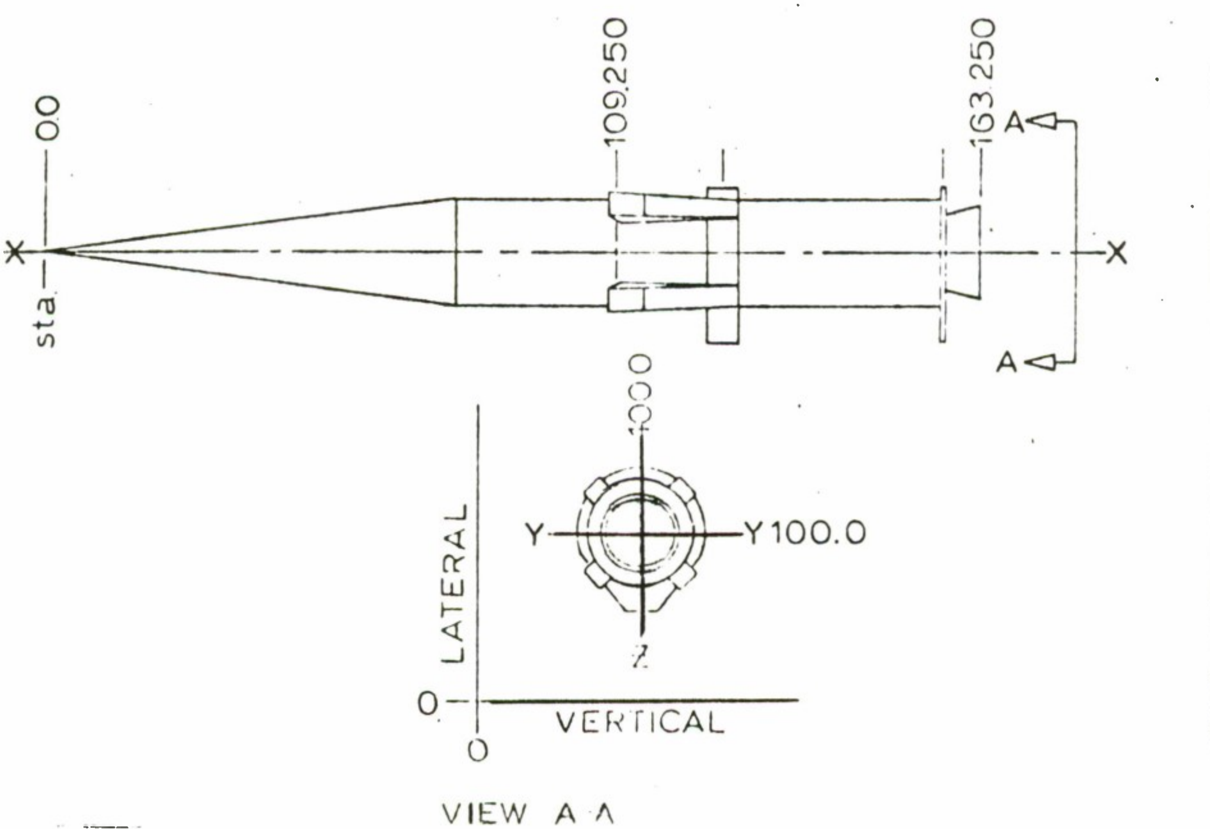


TABLE III. SLED TEST ENGINE

SUMMARY OF STIFFNESS COEFFICIENTS AT STATIONS 126.4 AND 154

	Centerline Deflections			
	Sta. 126.4		Sta. 154	
Unit load	D(in/lb)	θ (Rad/lb)	D(in/lb)	θ (Rad/lb)
Lateral	1.8×10^{-6}	4.28×10^{-8}	3.7×10^{-7}	2.76×10^{-8}
Vertical	2.54×10^{-7}	-	1.14×10^{-7}	-
Torque	10.05×10^{-6}	3.76×10^{-9}	2.76×10^{-8}	2.76×10^{-9}

Notes: (1) Reactions are calculated for unit loads at payload centerline
(2) Deflections are per in. lb.
(3) For torque "D" in lateral deflection of payload ℄ (in/in-lb).
"θ " is rotation of payload ℄ (rad/in-lb).

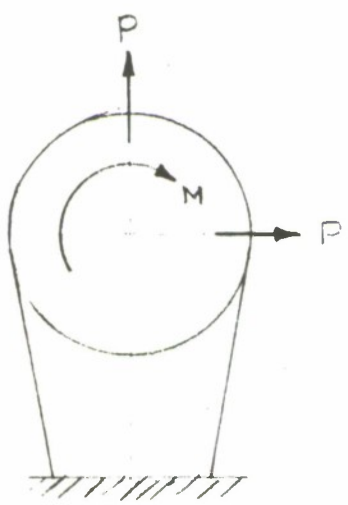
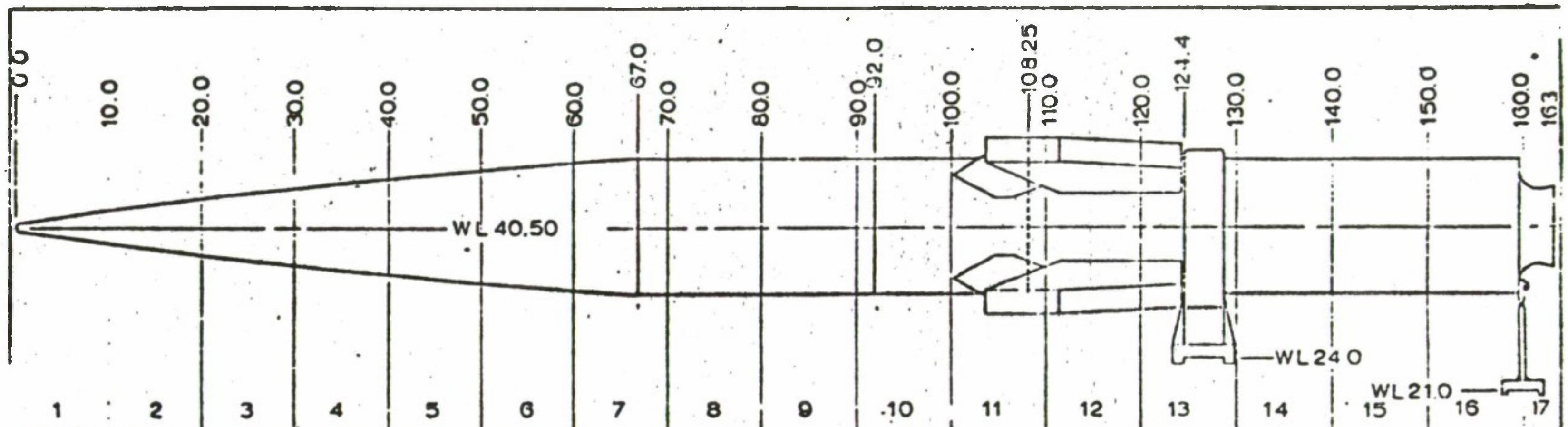


TABLE IV . PAYLOAD DEFINITION



REMARKS: Attach fittings to be revised -- moved upward.
Weights and inertias will change in sections 13, 16 and 17.

SECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
WT.	4.431	11.867	11.217	8.370	9.240	9.940	35.853	19.020	13.247	35.168	23.704	58.559	349.44	12.440	12.44	49.856	50.511
$\bar{X}$	6.638	15.390	24.557	35.379	47.163	52.990	67.154	73.667	85.00	93.586	105.447	115.416	125.137	135.00	145.00	158.413	160.393
$\bar{Y}$	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
$\bar{Z}$	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	31.684	40.50	40.50	26.800	30.500
Ix-x	6.58	71.66	119.66	172.82	298.04	368.85	1743.81	999.80	735.28	1756.19	830.60	3520.32	29855.10	684.89	684.89	4479.00	8415.60
iy-y	43.36	133.63	120.21	121.08	235.06	288.66	1029.03	689.73	478.04	1051.32	565.51	1760.20	23040.30	342.50	342.50	3890.90	8206.40
iz-z	43.36	133.63	120.21	121.08	235.06	288.66	1029.03	689.73	478.04	1051.32	565.51	1760.20	14927.50	342.50	342.50	2239.50	4207.80

TOTAL WTi	$\bar{X}$	$\bar{Y}$	$\bar{Z}$	ix-x	Iy-y	Iz-z	Ixz	
715.294	115.278	-0-	34.532	15.29	183.51	177.06	-17.81	Slug Ft^2

HI SPEED PILOT PROP. TEST SLED PAYLOAD WEIGHTS & MASS PROPERTIES DATA

J. A. Riehle 10-29-71

TABLE V. LIMIT DESIGN LOADS PAYLOAD

PAYLOAD STATION	SHEAR - LB.				BENDING IN - LB.	
	LATERAL		VERTICAL		YAWING	PITCHING
6.648000	412		641		0	0
15.39000	1188		1840		3611	5743
24.55700	1609		2494		14495	22770
35.37900	1689		2638		31903	50017
47.16300	1580		2497		51786	81433
52.99000	1401		2221		60968	96000
67.15400	660		1348		80658	127924
73.66700	688		1901		83485	132277
85.00000	900		2583		83012	131793
93.68600	1631		4314		80325	128193
105.4470	2057		5503		69348	119436
115.4160	2821		7908		60051	126791
125.1370	5569		19886		53953	168131
126.3999	5569	7072	19979	36,471	52725	184832
126.3999	1503		16492		52725	489829*
135.0000	1541		16248		39825	363310
145.0000	1574		16086		24479	219159
158.4130	1887		15966		3603	28181
160.4000	1887	2823	15916	17,403	290	443
160.4000	936		1487		290	443
160.6980	0		0		0	0

*Based on ℄ transducers 12 in. below ℄ payload.

TABLE VI . LIMIT DESIGN LOADS ~ LOAD CELLS

PAYLOAD STATION	ITEM		UNITS	RANDOM LOADS		RANDOM LIMIT LOADS	QUASI-STEADY LOADS	DESIGN LIMIT LOADS
				CORRELATED	UNCORRELATED			
6.64	Deflection		In.	0.096	0.093	0.789		
126.4	Axial Force		Lb.	6,770	5,630	12,400	14,000	26,400
	Lateral Force		Lb.	2,860	2,690	5,550	0	5,550
	Vertical Force		Lb.	12,650	12,200	24,850	8,300	33,750
	Bending Moments*	Pitching	In. Lb.	732,000	118,000	250,000	240,000	490,000*
		Yawing	In. Lb.	30,600	22,800	53,400	0	53,400*
160.4	Lateral Force		Lb.	1,330	1,190	2,520	0	2,520
	Vertical Force		Lb.	4,020	3,440	7,460	7,100	14,560
	Torque		In. Lb.	29,100	25,300	54,400	0	54,400

*Acting at Payload ℄ only. All other loads acting through the ℄ of the transducers.
℄ Transducers are 16 in. below ℄ payload at Sta. 126.4

NOTE: 1. Transducers assumed pinned in fore and aft direction.
2. Torque based on shear transfer of 12 in. from ℄ payload to ℄ transducer minus roll inertia. Troque will be increased for 16 in. shear transfer.

Quasi-Steady State Plus Random
Two Sigma (2σ) Level, Average of Fully Correlated and Uncorrelated

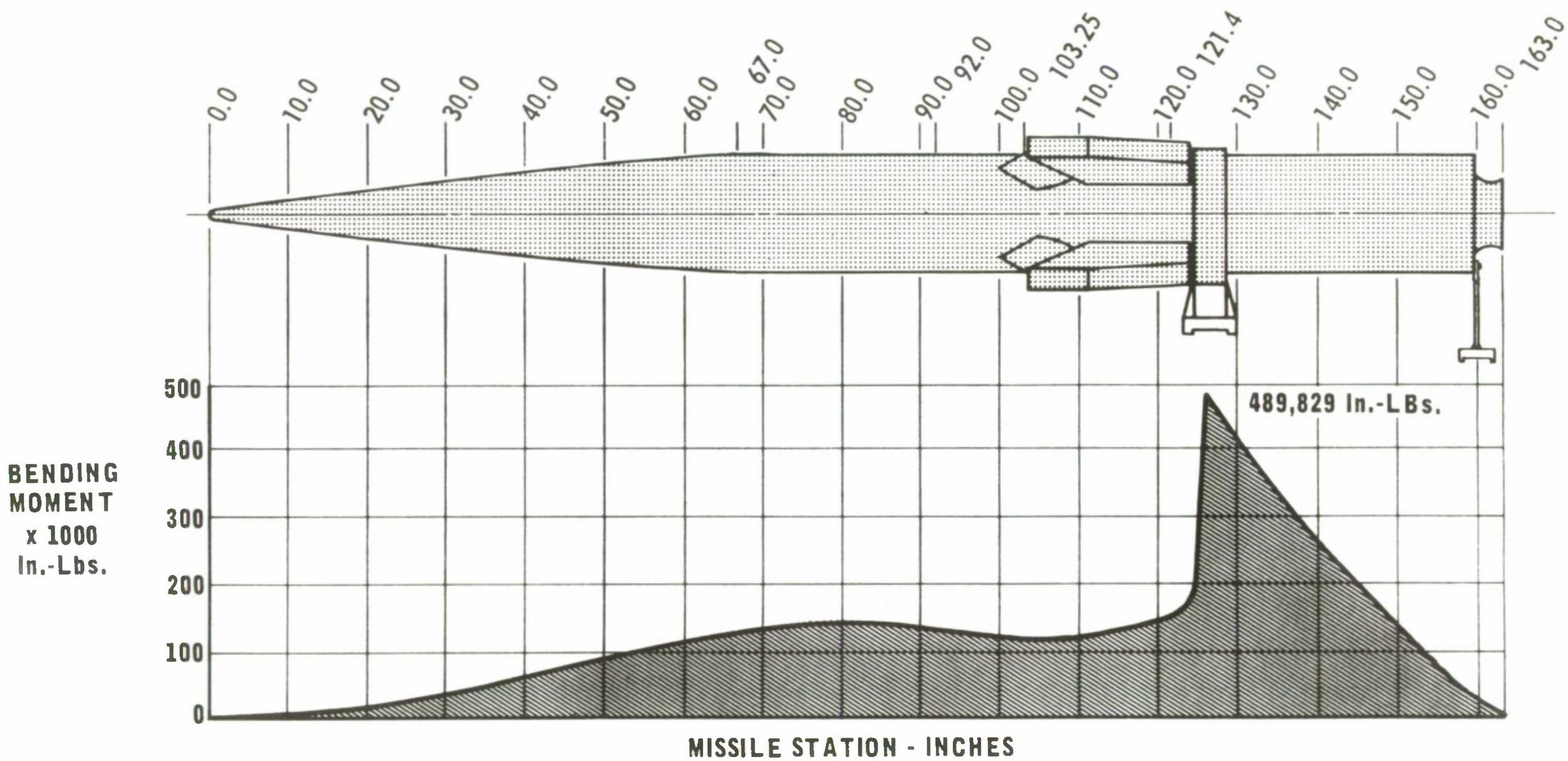


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Figure 7. Bending Moment.

As shown, the primary structural design requirement is at Station 124.4 where the forward support mount is located.

From Figure 8 , it is seen that the maximum shear reactions also occur at Station 124.4 where the forward support is located. Significant modification to the LASRM structural joint in this location was made to provide a positive margin of safety. A flanged joint with twenty-four (24) 1/2-inch diameter bolts was used in the modified design.

The results of the stress analysis are shown in Table VII , Margin of Safety. The sled test engine and mounts were considered satisfactory for the structural requirements.

The stress analysis was performed as follows:

STA. 124-4 - The load cell at station 124.4 was considered to be pinned with respect to axial loads, and rigid for lateral loads. Consequently, the axial reaction to the payload caused a pitching moment at the center-line of the payload at station 124.4. The lateral load from the payload caused a moment at the load cell equal to the shear transfer less roll inertia. The lateral moment is further reduced by the assumed lateral moment distribution between the forward and aft load cells.

It was assumed that 70% of the total torque about the centerline of the load cells would be reacted by the forward load cell and 30% by the aft load cell. This assumption, although arbitrary, should result in convervative loading of the mount at Station 124.4

The analysis of the mount frame at the station 124.4 was simplified by the assumption of inflection points. Because of the rapid change in section properties at the frame leg junction with the payload flange rings and approximately equal I/L of the base plus load cell and the ring flanges, the inflection point would most likely be at frame leg junction with the ring flanges.

The inflection points were assumed for the loading resulting from the lateral and vertical loads only. The axial loads are transferred from the centerline of the load cell directly to the payload centerline causing a linear variation in moments up the frame from the load cell.

Plastic bending effects were used to increase the equivalent bending stress allowables where applicable. It was considered that even though the random vibration contributes somewhat more than one-half the design limit loads, the plastic bending increase is equivalent to the allowable stress for very rapid strain rates.

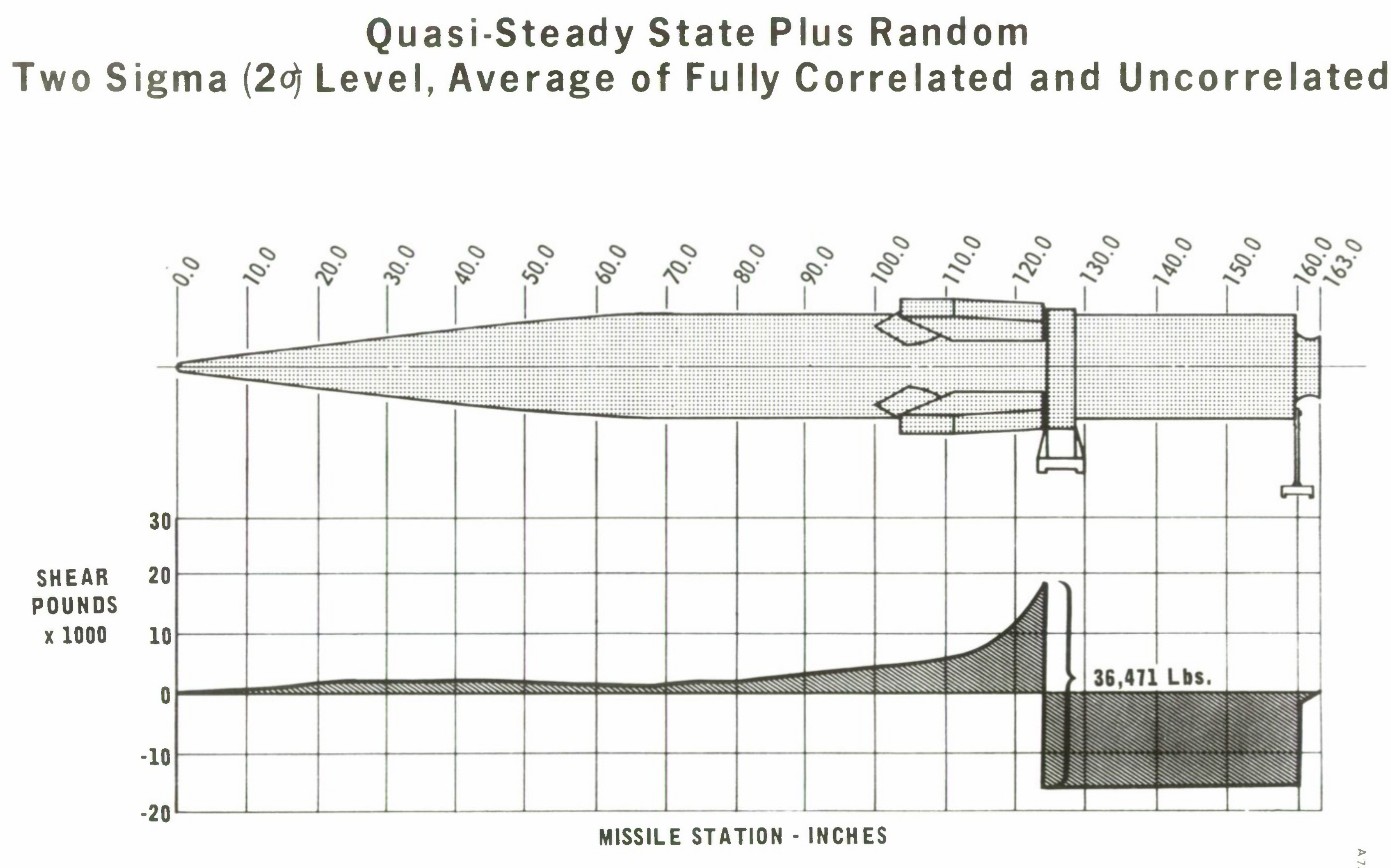


Figure 8. Design Shear Loads.

TABLE VII. MARGINS OF SAFETY

LASRM SLED TEST ENGINE

Part number	Part name	Remarks	Stress (ksi) or load (k)	Margin of safety
Sta. 124.4	Mount	At Inflection Point	109	0.15
	Frame Attach Bolts	At ℄ Payload	88	0.10
	Rings	Combined Rings in Bending	6.5	Large
	321 CRES Flange	Bending at Weld	16.7	0.62
	Doubler	Tension on Doubler at Weld	47.4	0.34
	Base	Bending at Bolt Holes with 1.75 K	144.0	0.05
	Sear Pins in Base	3 Pins Only 1.5 Ultimate Factor	68.5	0.37
Sta. 130.0	Tailpipe	Bending Plus Internal Pressure	45.8	Large
Sta. 160.4	Flexure	Combined Bend Plus Compression at Base 1.25 Ultimate Factor	$R_{(b\&c)} = 0.972$	0.03
	Bolts to Load Cell	Max. Tension Load to Bolt 1.5 Ultimate Factor	4.75	Large
	Base	Bending on Base from Bolt Load	38.1	Large
Sta. 109	Doubler	Bending and Tension in Doubler	39.7	0.77

The bolts connecting the various flange rings and the mount frame of the station 124.4 were analyzed for the combined tension and shear loads resulting from the body bending moments and the frame shear loads. It was conservatively assumed that not all the flange bolts were effective in resisting shear. Actually, the mount frame helps to distribute the shear since it pilots the body rings.

STA. 130 - The tailpipe was analyzed for the shear and bending caused by the reactions at station 160.4 in combination with the ramjet pressures.

STA. 160.4 - In addition to the loads specified by North American-Rockwell, the mount of station 160.4 must accommodate a thermal expansion of the tailpipe calculated to ± .15 inches. This was accomplished by treating the thin plate as a flexure fixed at the top and bottom.

An equation was developed expressing the maximum combined stress in terms of "t" for the flexure. This equation was differentiated and set to zero to obtain the minimum stress as a function of "t". The second equation was then solved for the value of "t" that would satisfy the equation. The calculated optimum value of "t" was a little bit greater than an available stock size of .125 inches. The smaller value of .125 in. was then used to obtain the least value of axial load on the tailpipe due to flexure loads.

Because half the vertical load of station 160.4 is due to quasi-steady loads, the flexure plate was analyzed for column buckling combined with bending. Margins were conservatively obtained by combining column stresses with maximum bending stresses at the fixed ends. The flexure is a beam column, but since the fixed ends and the inflection point will not deflect axially as a result of load, no secondary bending will develop.

The loads and stresses on the base attachment bolts were low.

c. Forward Support Mount

The payload primary support is at Station 124.4 where essentially all of the loads are taken through the forward mount. A schematic of the final design for this support mount is shown in Figure 9 . The forward mount ring, support legs, and base are formed from a single piece forging of 4340 steel. After rough machining, the material was heat treated (1700°F) to 160 Ksi. Final machining to dimension was made after heat treat. Twenty four 1/2 inch diameter bolts attach the test item to the forward mount.

A summary of the stiffness coefficients for the modified forward support mount is given in Table VIII.

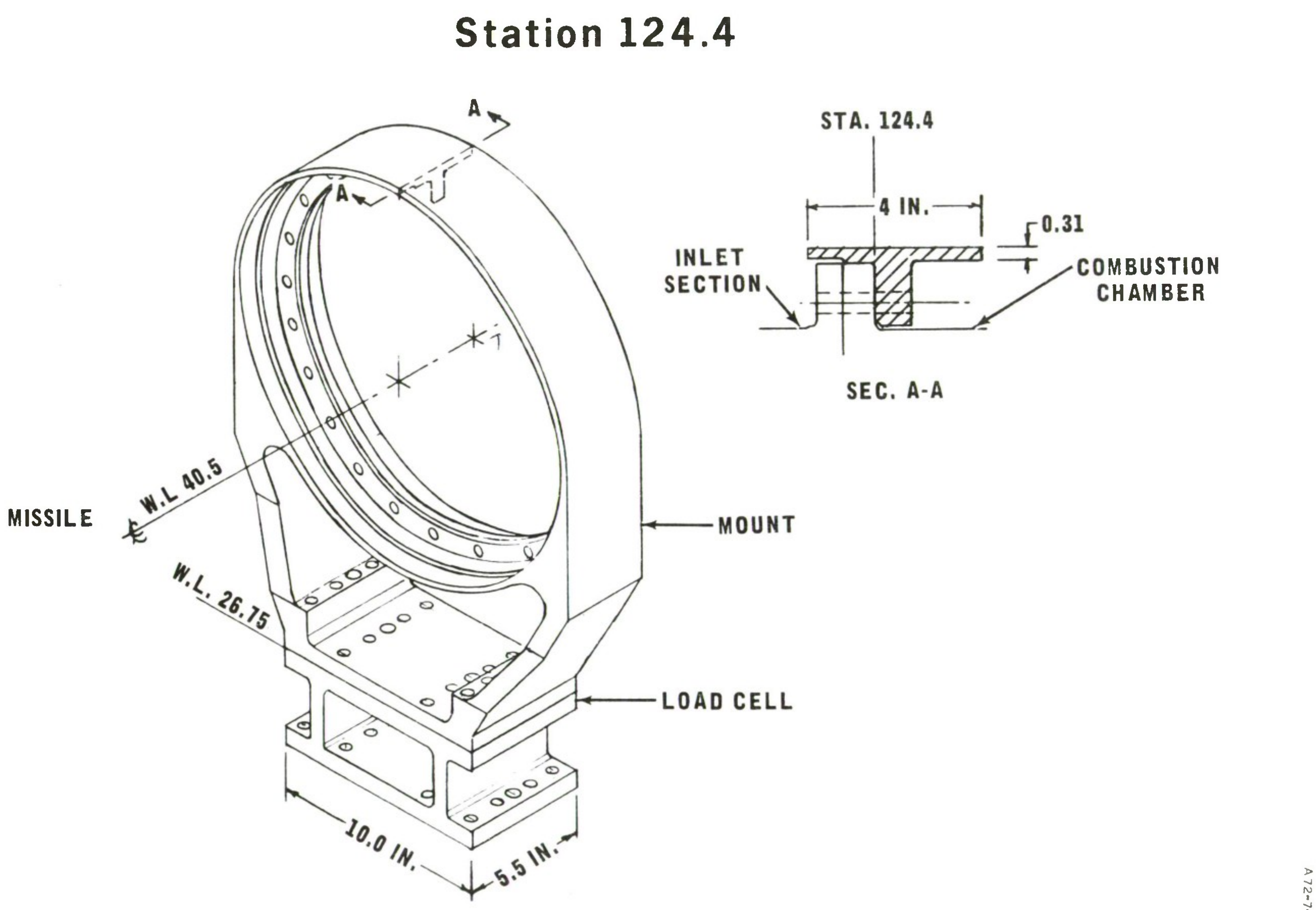


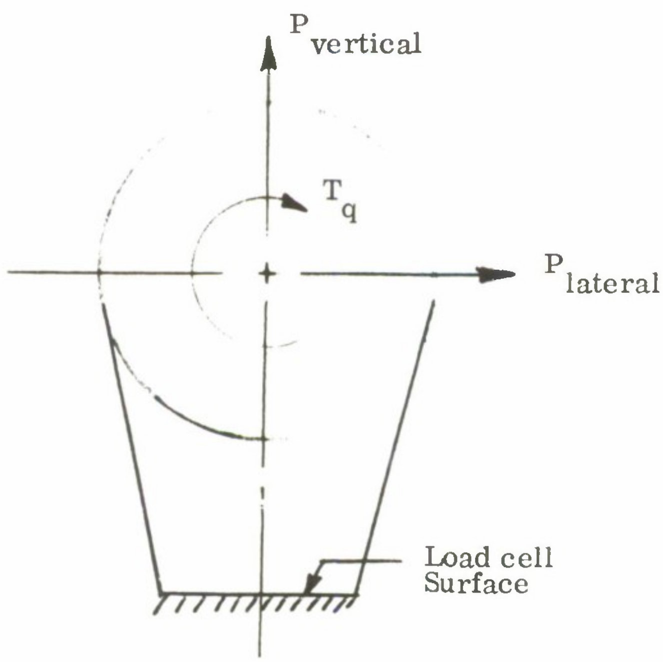
Figure 9. Forward Support and Load Cell.

TABLE VIII. SUMMARY OF STIFFNESS COEFFICIENTS OF STATIONS 125.525 AND 160.028 FOR UNIT LOAD AT CENTERLINE

	Station 125.525		Station 160.038	
Unit Load	D(in/lb)	θ (rad/lb)	D (in/lb)	θ (rad/lb)
Lateral	10.71×10^{-6}	$.501 \times 10^{-6}$	1.44×10^{-6}	$.109 \times 10^{-6}$
Vertical	1.54×10^{-6}	-	$.199 \times 10^{-6}$	-
Torque (a)	0.503×10^{-6}	$.0250 \times 10^{-6}$	$.109 \times 10^{-6}$	$.0112 \times 10^{-6}$

(a) Deflections are per in-lb.

Note: Deflections are at Payload centerline.



The design of the forward mount incorporates several features: (1) low drag profile, (2) high load carrying capability for its total mass, (3) the open area between the support legs and base provides air flow passage to maintain an aerodynamically clean flow field around the payload, (4) shear loads between the mount and the load cell are taken out by four 1/2 inch diameter shear pins thus eliminating the need for close tolerances on the bolts and bolt holes interfacing the mount of the load cell supplied by the University of New Mexico.

The forward support mount interface to the sled is made through a load cell. Particulars for this load cell are:

Dimensions:	5-1/2" x 10" x 3-1/2"
Attachment:	16-3/8" ϕ bolts
Alignment:	4-1/4" ϕ shear pins for shear loads

Bottom of Load Cell located at Water Line 22.75.

d. Aft Support

The aft mount consists of an indexed ring that attaches to an existing flange and bolt circle on the flight engine combustion chamber at station 159.84. The ring was welded to a flex plate support to accommodate thermal growth in the engine assembly during test. The 1/8-inch thick flex plate was indexed and welded to a base plate. The base plate interfaces with the load cell supplied by the University of New Mexico through eight bolts and two 5/16 inch diameter shear pins. All materials for the ring, flex plate, and base are 4130 steel.

The magnitude of the loads to be reacted at the aft end permitted a simplified light weight design to be adapted. The flex plate support is in common use by Marquardt in the test facility at Van Nuys. A schematic of the final design is shown in Figure 10 . The stiffness coefficients for the support mount are shown in Table VIII. Details of the stress analysis are given in Appendix D.

e. Fuel System

Criteria for the fuel system required the system to be totally contained within a volume that is fourteen (14) inches long, eighteen (18) inches high and twelve (12) inches wide. This volume contained the fuel supply, pressurization system, engine supply line, valves and controls. A one and a half (1.5) inch internal conduit was provided from this volume to the area of the vehicle mount. Fuel flow initiation and shut-off was controlled from track side knife edges. The fuel system provided a fixed fuel flow for fuel air ratios of 0.02 to 0.04 for at least six (6) to eight (8) seconds for Mach number ranging from 2.3 to 2.7. The fuel flow was set to provide "a given flow rate" for any given test run. Procedures for fuel system installation and removal are given in Appendix A.

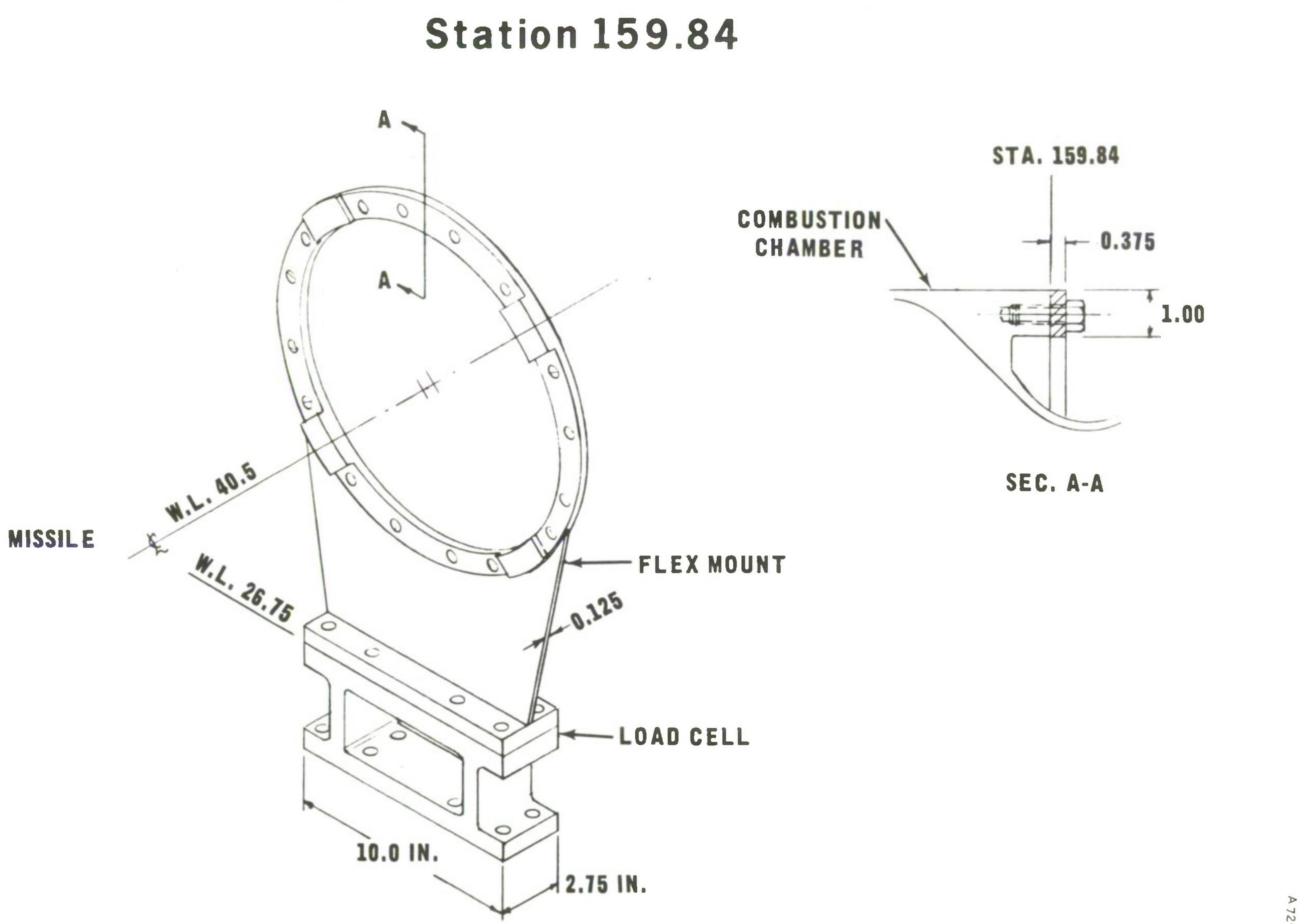


Figure 10. Aft Support and Load Cell.

The palletized fuel supply and flow control system was located in the test sled just aft of the forward support mount. As shown in Figure 11, the overall dimensions of the package are 10-3/4 inches by 12 inches by 11 inches. With the exception of the fuel supply tank, the same components were used as were used on the LASRM fuel control. The fuel tank operating supply pressure is 1000 psi (nitrogen). The nitrogen pressure supply was contained within two (2) 5-1/2 inch diameter by 12-1/2 inch long bottles. The bottles, located in an aft compartment on the sled, provides 370 cubic inches volume. Capacity of the fuel tank is 1.7 gallons. An elastomeric bladder is contained within the tank to provide a positive flow of fuel under all acceleration conditions. Fuel was collected at the bottom of the tank by means of a cruciform manifold with multiple openings to preclude premature fuel stoppage by the collapsing bladder. The nominal fuel flow rate was 1.1 pounds per second which provided approximately 12 seconds fuel flow. A schematic of the fuel system is shown in Figure 12 .

On-off control was effected by a normally closed solenoid valve. Flow rate was manually set and controlled by a Manatrol flow control valve. Checkout of the fuel supply system and flow control was accomplished at Marquardt-Van Nuys. The calibration curve for the fuel flow regulator is shown in Figure 13 . Dynamic characteristics of the fuel control are shown on the oscillograph trace of Figure 14 . As shown, full flow (1.195 pps) is achieved approximately 0.2 second after power signal to the fuel valve.

f. Ignition

The ignition system is the same unit as was used on the SCP/LASRM flight test. A pyrophoric material, TriEthyl Borane (TEB), is injected into the combustion chamber in the region of the fuel injection. A photograph of the igniter system is shown in Figure 15 .

The TEB igniter is a self contained unit located under an inlet aft fairing. Pressure is supplied by a charge of nitrogen contained within the TEB tank. TEB flow is signaled electrically by the operation of a normally closed explosive valve initiated by a Conax No. 1802-111-01 dual bridge, single charge squib. Procedures for Igniter System loading are given in Appendix B.

Capacity of the TEB tank is one-fourth pound and supplied a TEB flow for approximately three seconds.

g. Instrumentation

The primary objective of the propulsion system instrumentation was to determine the performance of the inlets, fuel system, igniter and combustor nozzle to allow for the comparison of sled track test data with both ground freejet and flight test data.

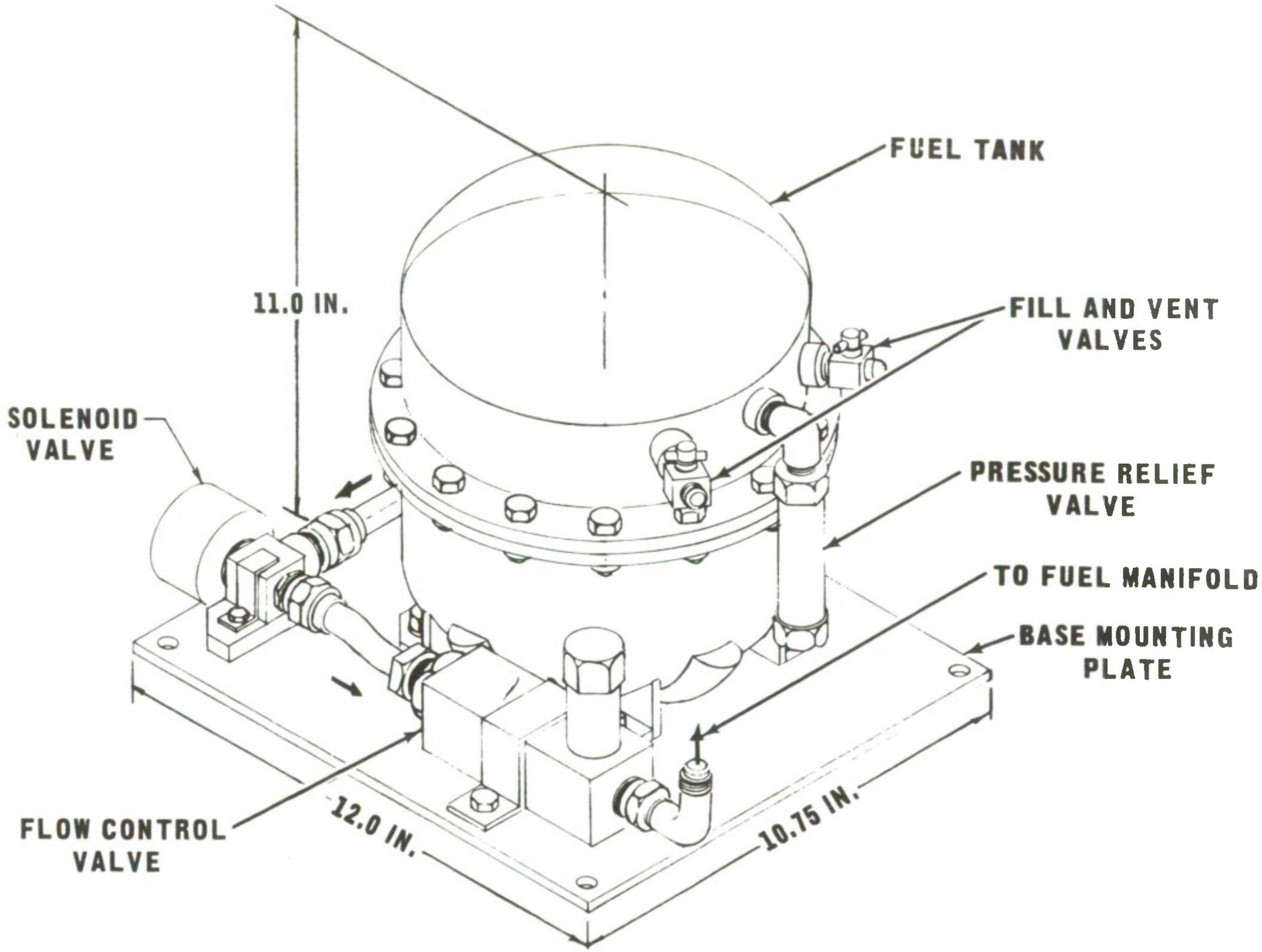


Figure 11. Fuel Supply System.

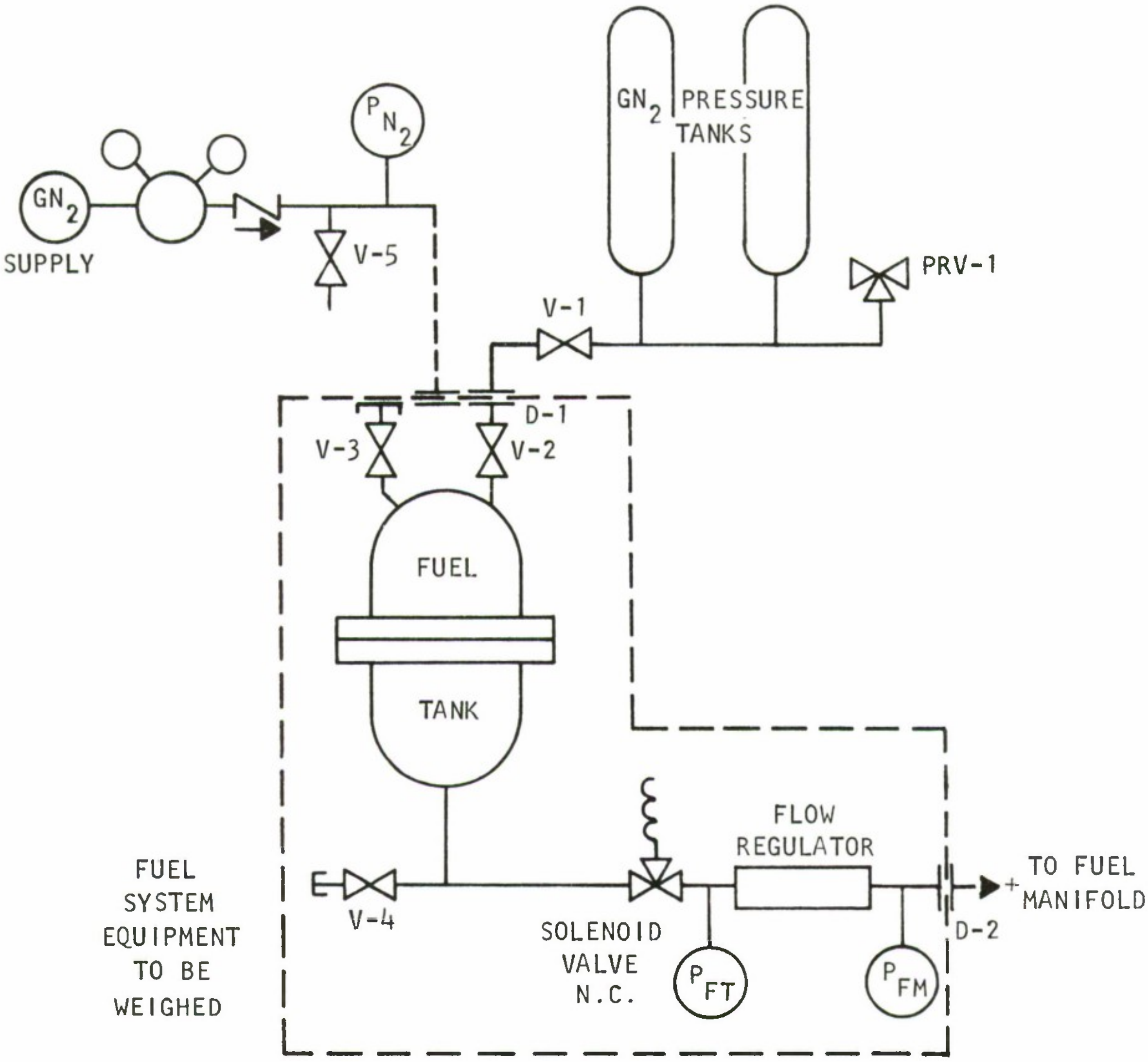


Figure 12. Fuel System Schematic.

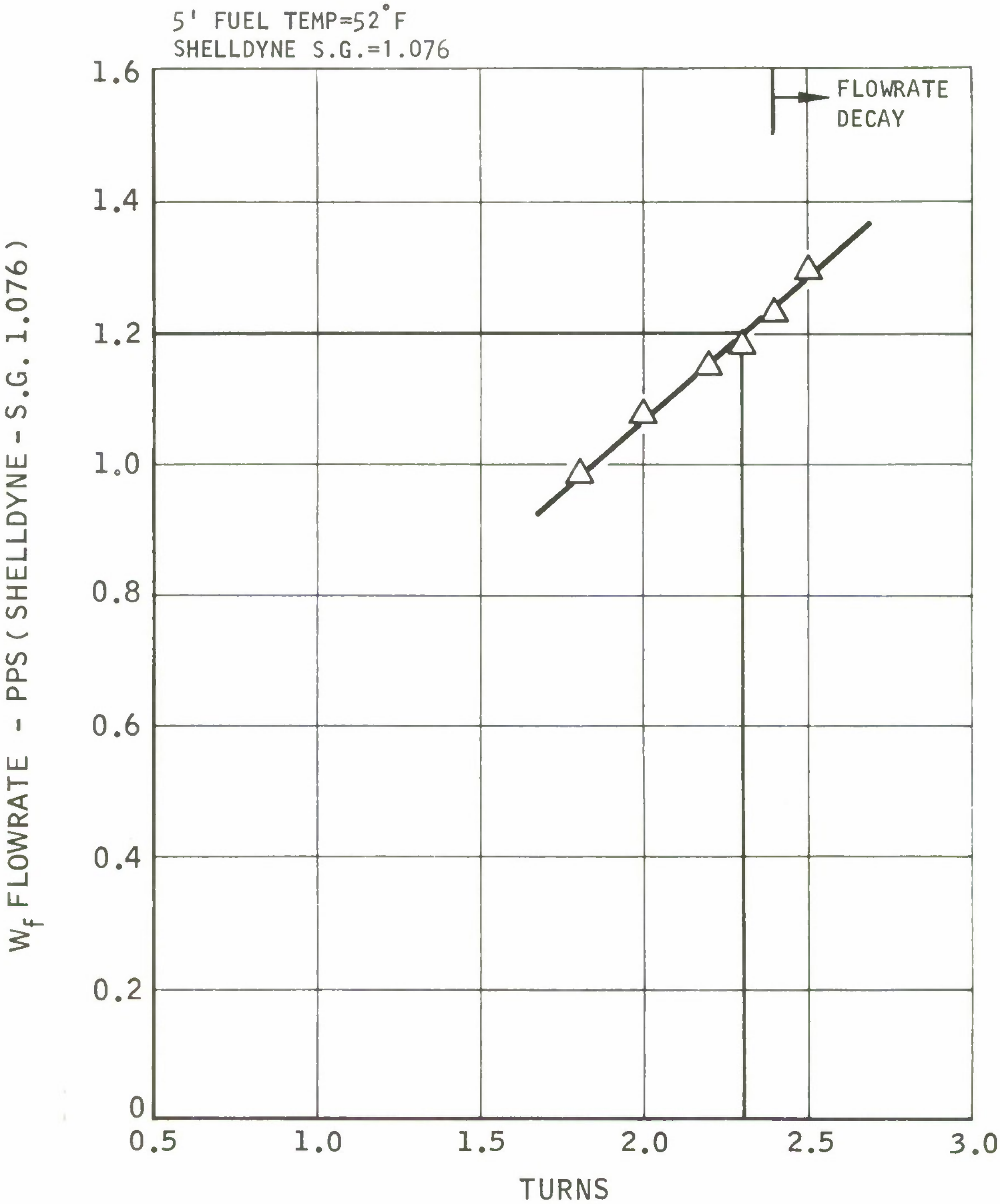
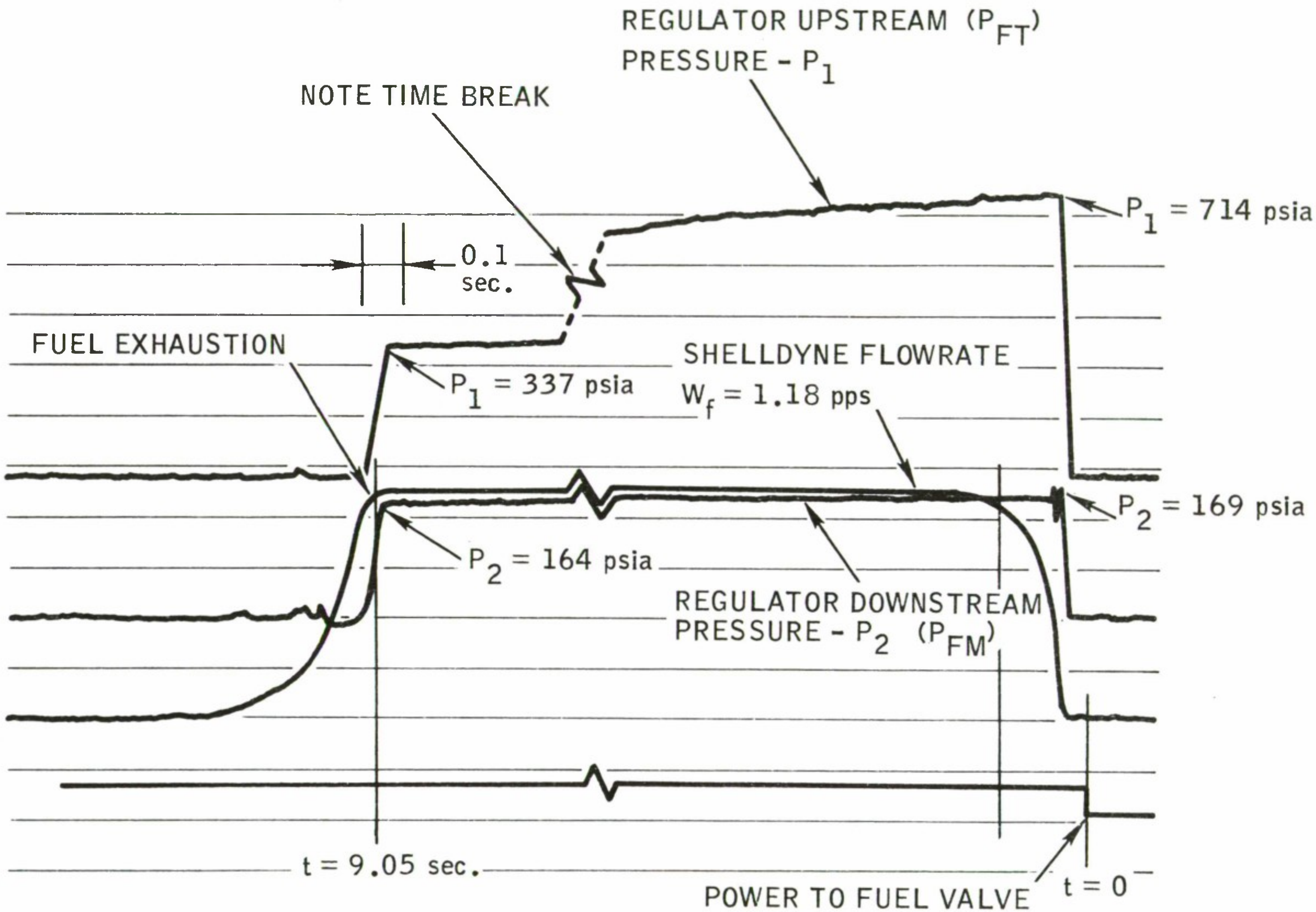


Figure 13. Regulator No.2 Calibration.



REGULATOR SETTING - 2.3 TURNS

Figure 14. Characteristics Of Sled Test Fuel System.

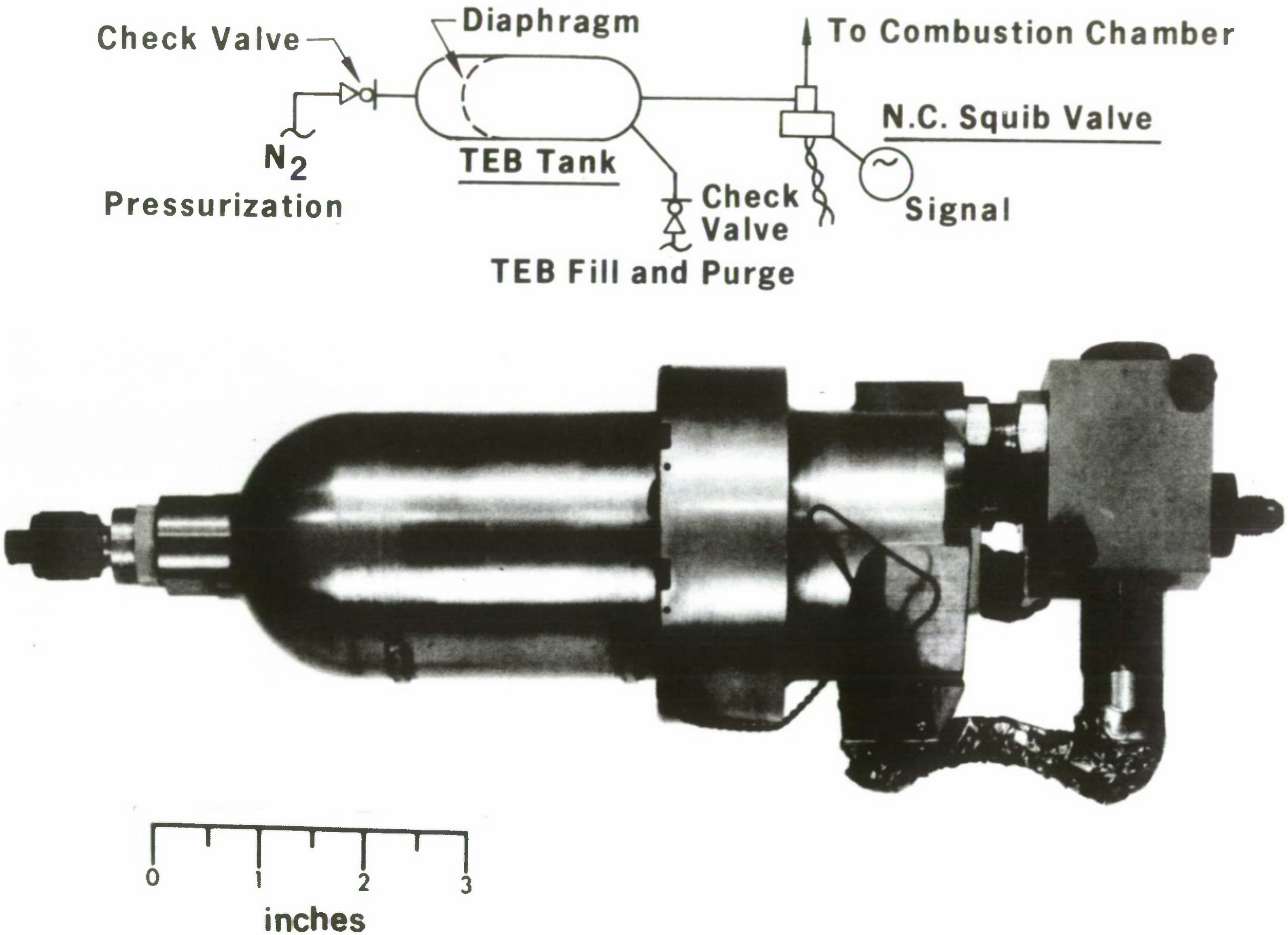


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Figure 15. Igniter

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During the cold flow (non-combustion) test runs, eleven (11) instrumentation channels were assigned to propulsion. Eight (8) of these were identified as diffuser static pressure probes and located as shown in Figure 16 . Four taps at Station 4 just upstream of the exit nozzle in the combustor were manifolded together to provide combustion chamber pressure. Fuel tank pressure and fuel manifold pressure completed the propulsion system instrumentation. The types of instruments used and their ranges are shown in Table IX . As noted, the anticipated static pressure during non-combustion runs is less than half the transducer range. For these runs, the sensitivity was set to provide full scale deflection at half the transducer range.

The sequencing for the combustion test runs is shown in Section C of Table IX . This sequence is based upon reaching design velocity (2530 fps) at T + 7.525 seconds.

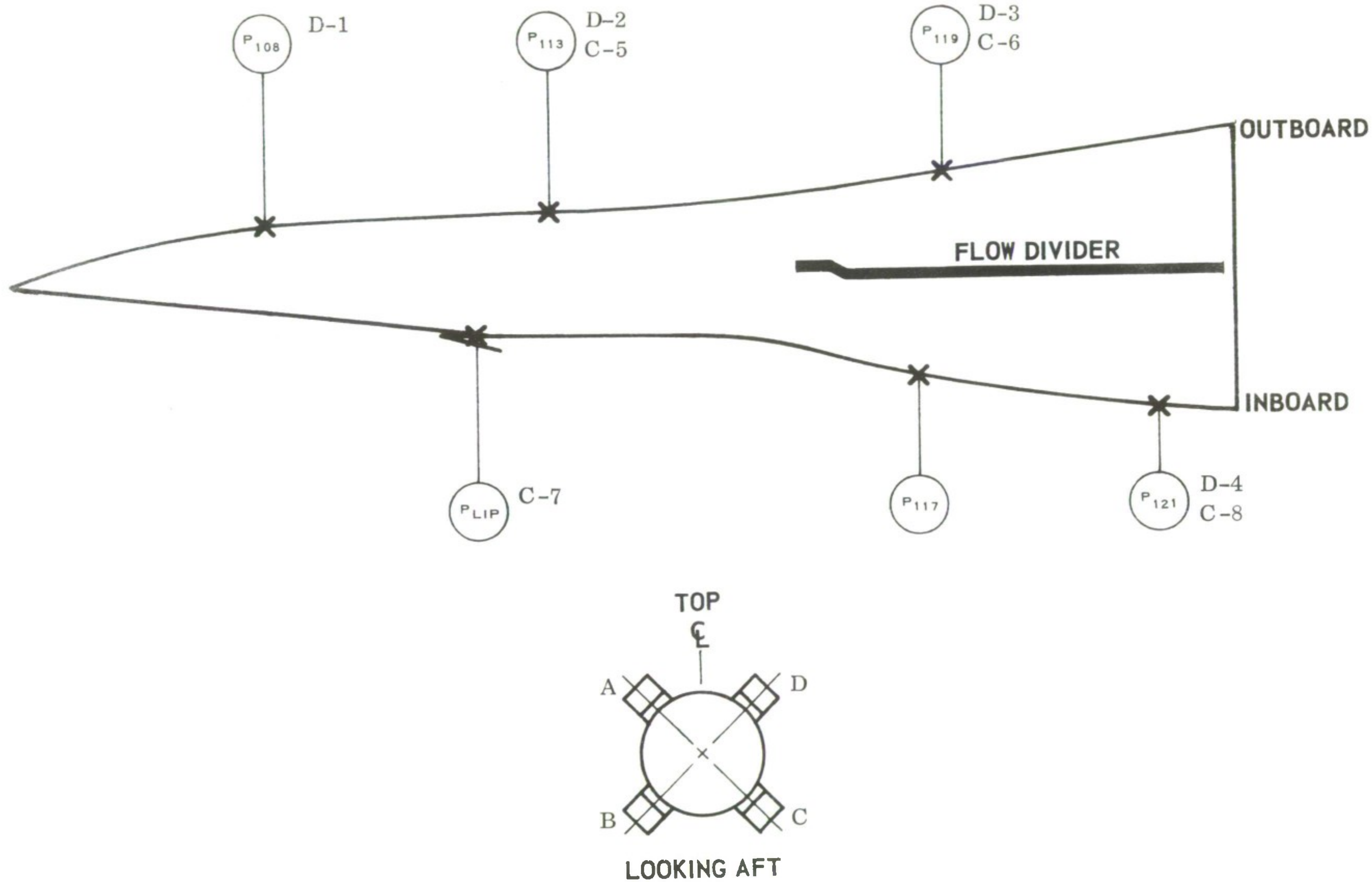

Figure 16. Diffuser Instrumentation

TABLE IX . PROPULSION SYSTEM DATA REQUIREMENTS FOR TEST RUNS 4 THRU 7 OF HIGH SPEED PILOT PROPULSION TEST SLED TRACK PROGRAM

A. INSTRUMENTATION

No.	Measurement	Missile station	Type Instrument	Range psia	Sensitivity psia/volt Cold flow	Hot flow
P108A	Inlet A Static	108	Statham PA850	150	10	20
P_{lip} B	" B "	111				
P113A	" A "	113				
P113B	" B "	113				
P119A	" A "	119				
P119B	" B "	119				
P121A	" A "	121				
P121B	" B "	121				
P4	Comb. Chamb. Static	157				
PFT	Fuel Tank Press.	Fuel Bay	CEC4-354	1000	200	200
PFM	Fuel Manifold Press.	Fuel Bay	CEC4-354	1000	200	200
E-FV	Fuel Valve On/Off	Fuel Bay	Marotta	-	-	-
E-TEB	TEB Valve On	Inlet C	Conax	-	-	-

Notes:

1. Calibration curves (mv/volt) for Statham transducers are based on 10 volts input.
2. Calibration curves (mv/volt) for Consolidated Electronics transducers are based on 5 volts input.
3. Maximum range of pressures expected for cold flow tests is 60 psia. Sensitivity is based on full scale deflection for 75 psia.
4. Maximum range of pressures expected for hot flow tests is 120 psia. Sensitivity is based on full scale deflection for 150 psia.
5. Fuel "ON" and TEB "ON" can be energized by same signal.

TABLE IX . (Contd.)

B. TELEMETRY DATA

Chart Paper Speed	4 in/sec
Filter	8 cps

IRIG B Time Line

Start-of-Motion Time

5 Channels/Chart

2-in Full Scale/Channel

0-75 psi. full scale deflection - Cold Flow Statics

0-150 psi full scale deflection - Hot Flow Statics

0-1000 psi full scale deflection - Fuel Press. Statics

No Mean Square Data

C. FUEL SEQUENCING

Assumption: Sled velocity reaches 2530 fps at T + 7.525 seconds

TEB ON	T + 7.2 seconds
FUEL ON	T + 7.2 seconds
FUEL OFF	T + 10.95 seconds

D. ELECTRICAL

TEB Valve:

Conax No. 1802-111-01

Dual Bridge Single Charge

No Fire: 1 amp/1 watt, 5 minutes

All Fire: 5 amp, 25 m sec, pulse

Response: 8 m sec nominal

15 m sec maximum

Resistance: $1.0 \begin{smallmatrix} +.02 \\ -.00 \end{smallmatrix}$ ohm/Bridge

Fuel Valve:

Marotta N.C. Solenoid

Operating Voltage:	16-30 vdc
Resistance @ 20°C:	25 $\Omega \pm 10$ Ω
Rated Current @ 24 vdc & 20°C:	0.96 amp
Duty:	Continuous

SECTION IV

TEST RESULTS

1. TEST PLAN

The test program is conducted in two phases: (1) cold flow structural tests, and (2) ramjet performance tests.

The cold flow structural tests were designed to provide a conservative approach to the determination of the structural adequancy of the test hardware and the applicability of the math model. These cold flow tests also permit confirmation of the velocity profile and verification of the ramjet ignition sequencing.

For the initial run, the "short forebody" configuration was 24 inches shorter than the LASRM vehicle ("long forebody"). The lower maximum velocity (1700 fps) was achieved by use of only the sustainer motor. The low velocity and shorter cantilevered length reduced the applied loads significantly for the initial run. The second test run was scheduled at the lower velocity, but with the full forebody length. A reasonable confidence in the structural integrity of the test item and in the applicability of the math model was obtained by the third run which was at full length and design velocity. A summary of the test plan is given in Table X .

The estimated trajectory for the initial test run using only the sustainer motor (MK 12 Mod 1) is shown in Figure 17 . The estimated velocity profile shows a maximum velocity of 1745 ft per second.

This low speed test run provided a hardware/facility/operations check without unduly jeopardizing the "one-of-a-kind" test item.

The predicted velocity profile for the complete propulsion test sled is shown in Figure 18. Test operation time is considered to be that time during which the sled is at Mach 2.3 or above. The effective operation time was estimated to be between 4 and 5 seconds. Maximum velocity predicted for the trajectory was Mach 2.7 to 2.8. After sustainer burnout, the sled is water braked using congealed water to a velocity below Mach 1.0; it is then allowed to coast over the section of track used to brake the second pusher sled, and is then water braked to a stop at the 35,000 ft. point of the sled track.

Three stages of boost operation were scheduled to provide the necessary acceleration. The two pusher sleds each carried four (4) MK 7 Mod 0 Terrier motors. At burnout of the first stage (3.2 seconds) the test assembly had accelerated to approximately Mach 1.0. At burnout of the second stage (6.4 seconds) the test assembly velocity was approximately Mach 2.2. The third, or sustainer stage, pushed the test sled to above Mach 2.3 and held it there for the desired time interval. The sustainer was a Mark 12 Mod 1 Terrier motor.

TABLE X . TEST PLAN

A. Cold Flow Structural Tests

Run No.	Configuration	Angle of Attack	Maximum Velocity	Date
1.	Short Forebody	0°	1700 fps	28 JULY 1972
2.	Long Forebody	0°	1700 fps	25 Sept. 1972*
3.	Long Forebody	0°	2800 fps	30 Oct. 1972*
4.	Long Forebody	4°	2800 fps	4 Dec. 1972*

B. Ramjet Performance Tests

Run No.	Configuration	Angle of Attack	Maximum Velocity	Date
5.	Long Forebody	0°	2800 fps	12 Feb. 1973*
6.	Long Forebody	4°	2800 fps	26 March 1973*

* Tentatively Scheduled for the Week Starting on These Mondays.

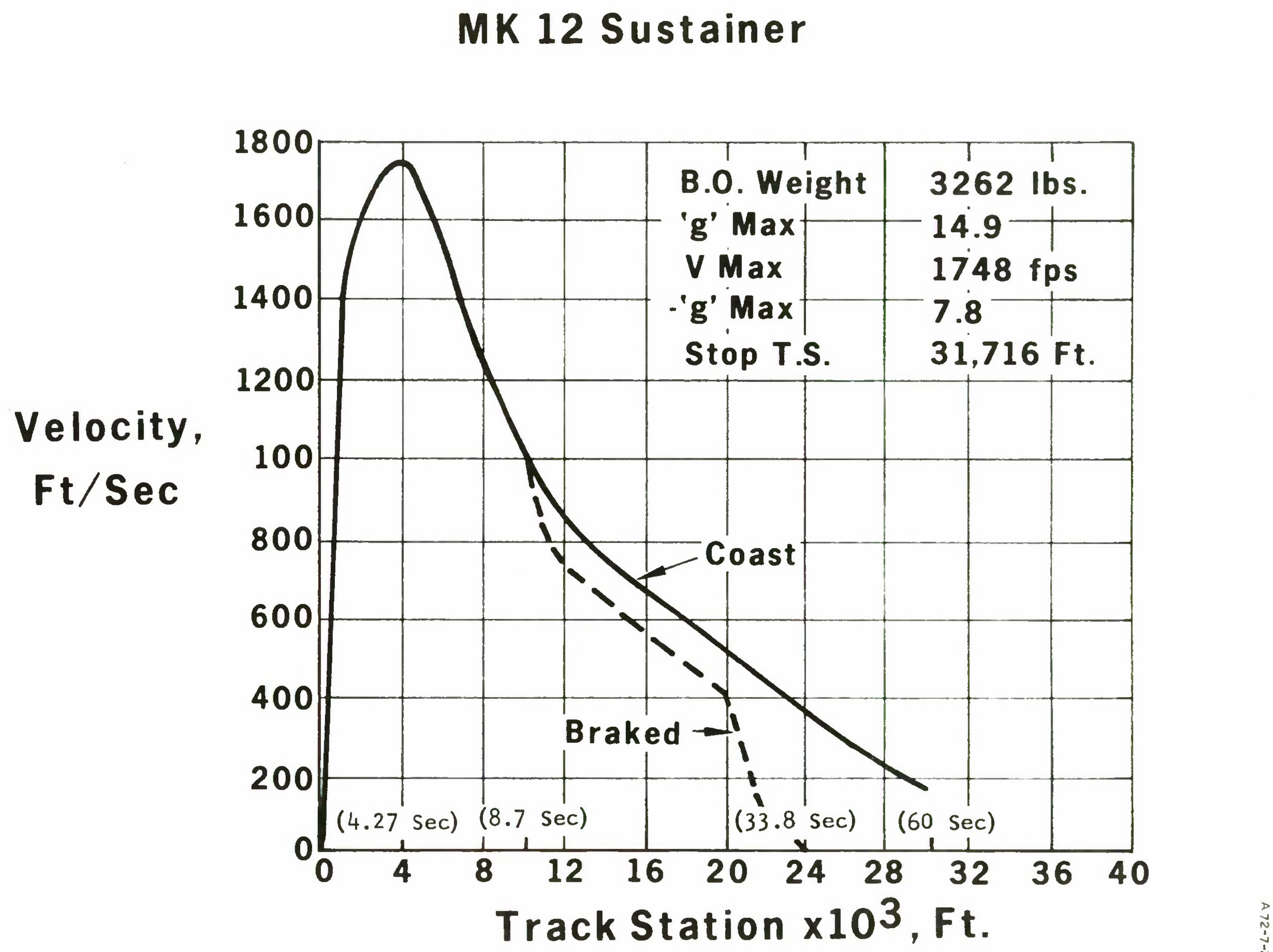

Figure 17. Run 1 Trajectory Estimate.

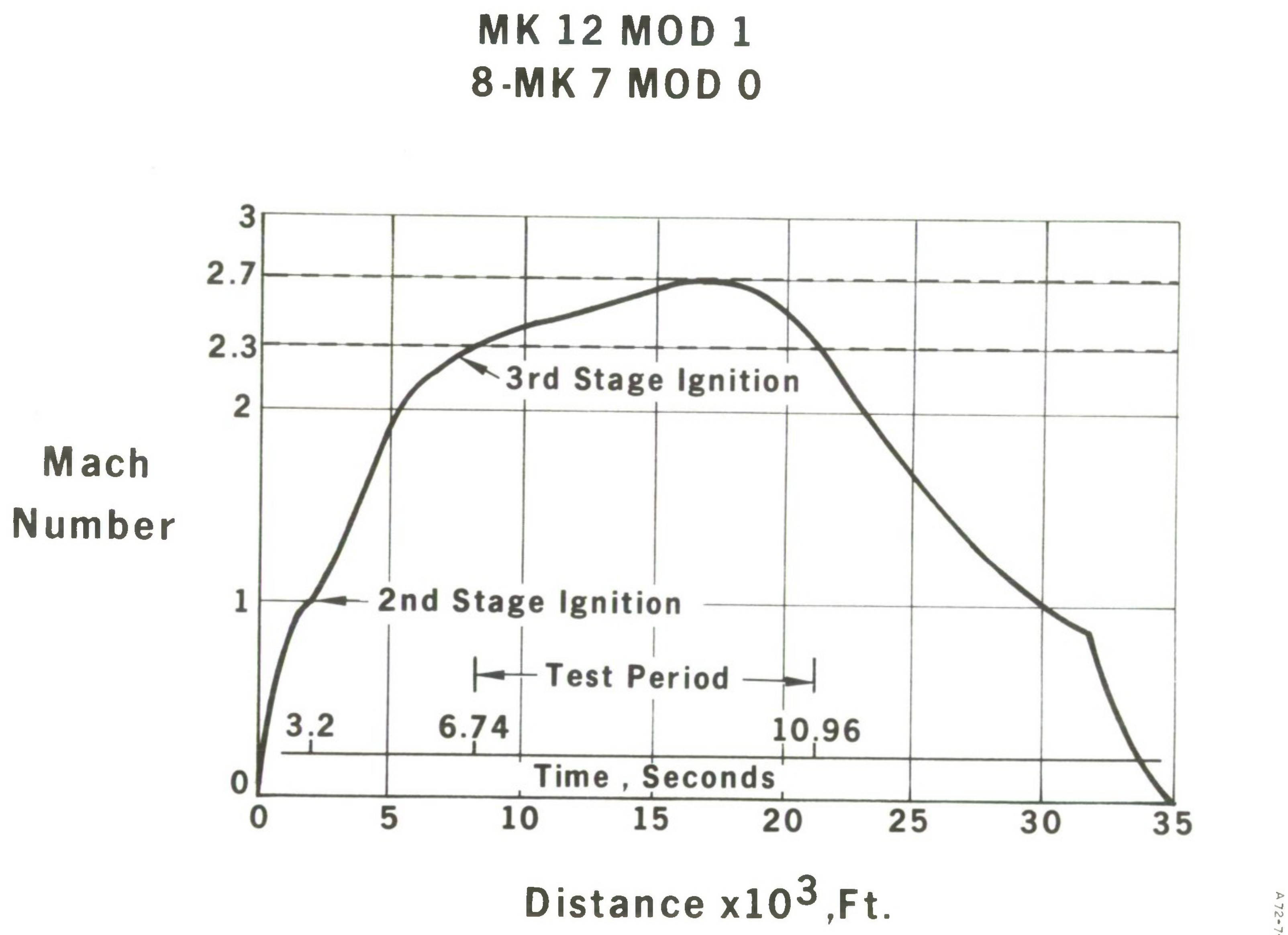

Figure 18. Aero-Propulsion Sled Trajectory.

2. TEST LIAISON AND ANALYSIS

The modified LASRM propulsion system was completed and delivered to North American-Columbus on 1 May 1972. Assembly and interface checkout to the modified sled was accomplished at the Columbus facility. Upon acceptance by the Air Force, the sled and propulsion first article were delivered to Holloman AFB for ground vibration tests. The test article is shown mounted on the test sled during the ground vibration tests conducted at Holloman AFB in Figure 19. The sustainer sled with a MK 12 case can be seen in position aft of the sled.

The first cold flow structural test was conducted successfully at Holloman AFB on 27 July 1972. Because of the scheduled low velocity of the test and the shortened forebody configuration, no propulsion instrumentation was included for this run. Maximum sled velocity during the test was approximately 25 fps short of the goal. However, test objectives were obtained in that the vibration and loads data obtained correlated with the Math Model.

Review of the propulsion hardware following the test showed no adverse effects of the test run. Based upon a linear extrapolation of the recorded data from the first test, NAR-C predicted loads at Station 109 for the second test (2000 fps) to be approximately 90% of design vertical load and 110% of design lateral load. At this velocity and with a 2.25 factor of safety, the stress analysis shows a positive margin at Station 109. On this basis, a go-ahead for the propulsion system was given to NAR-C.

The second cold flow structural test was conducted successfully at Holloman AFB on 20 September 1972. Because of the scheduled low velocity of the test, no propulsion instrumentation was included for this run. Review of the propulsion hardware following the test showed no adverse effects on the test run.

Station 109 was monitored during each run to determine the decrease in structural margin of safety with increasing velocity. Projected loads for Test No. 3 (2600-3000 fps) indicated a zero margin of safety at Station 109 with a 2.25 design factor. North American Rockwell, Columbus, requested permission to strengthen the joint to provide a positive margin at this design factor. It was agreed and doubler plates were installed between each inlet at Station 109.

In preparation for the third track test, Mr. R. Thompson was at Holloman AFB on 10 October to coordinate the installation of inlet splitter plates, pressure transducers, and the fuel supply N_2 pressurization tank.

The third track test took place on 27 October 1972. One of the objectives of this test was to provide velocities in excess of 2594 fps for approximately 3 seconds with a maximum velocity not to exceed 3046 fps. Inlets A and D were instrumented to provide cold flow static pressures. However, the maximum velocity actually attained on this test was 2487 fps. This is not sufficient to "start" the inlets (M_O 2.3 design point), so cold flow static data were not obtained.

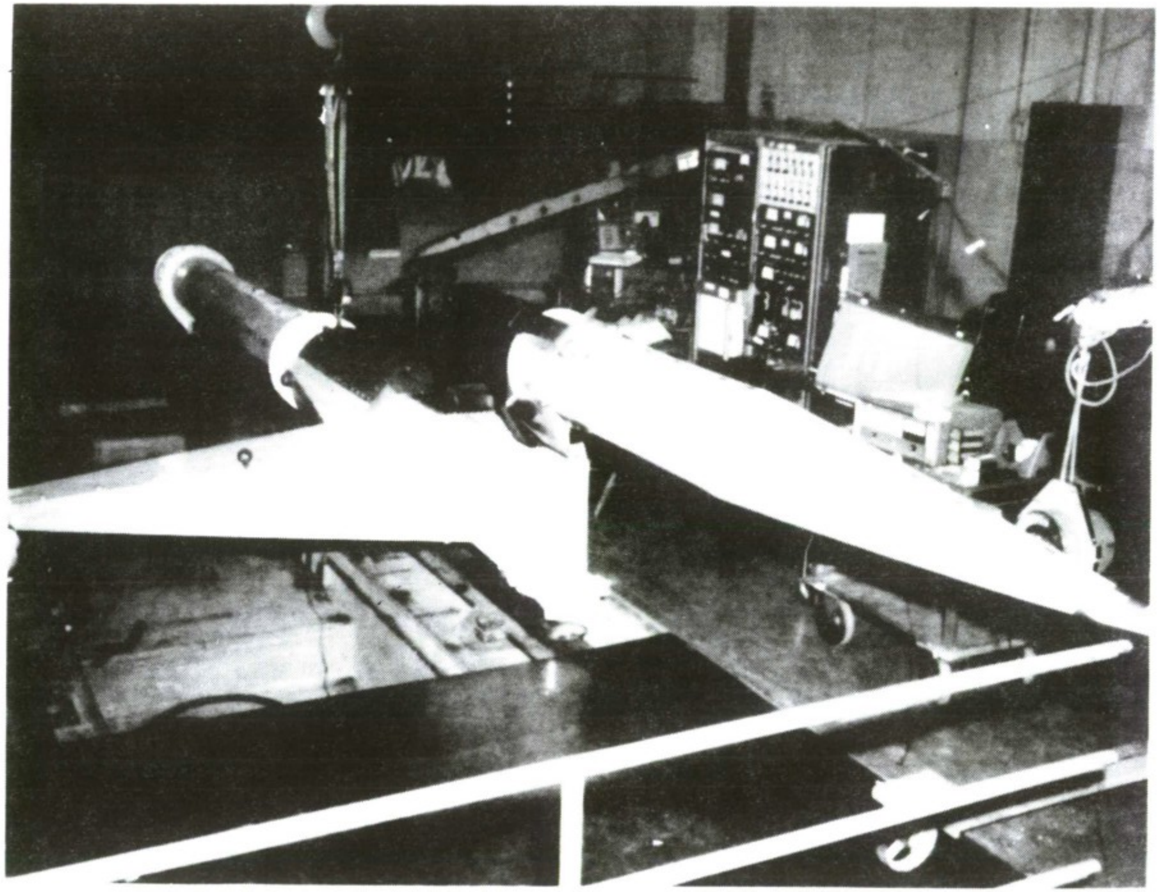

Figure 19. Ground Vibration Test - Holloman AFB

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Post test review of the test hardware showed a slight buckling in the aft flexure plate support. It is postulated that the aerodynamic drag load was the cause of the buckling. Two fixes were incorporated into the hardware prior to Run No. 4: (1) the aerodynamic shield upstream of the mount was extended to within 1/2-inch of the combustion chamber, and (2) the flexure plate was stiffened with 1/4-inch x 1-inch doublers along each edge.

The fuel tank, nitrogen pressure tanks, and necessary plumbing hardware were shipped to Holloman AFB via USAF Log Air on 7 December 1972. Installation and removal procedures were written and furnished to Holloman AFB for the Propulsion System Sled test ramjet engine fuel system. For the reader's information, these are incorporated as Appendices A and B to this report. A schematic of the fuel system is shown in Figure 12. The fuel system for the Propulsion System is prepackaged and requires a minimum of handling at the operations site.

Mr. R. Thompson was at Holloman AFB on 13 December to coordinate the installation of the fuel supply system and associated instrumentation. The inlet splitter plates were installed at this time; however, because of mechanical difficulties, they were not canted to the one degree ramp angle used during flight tests. Inlet capture area measurements were made and determined to be the same physical dimensions as used during freejet and flight tests.

Inlet cold flow data, as well as fuel flow data, were planned to be obtained during this run. The sled test was scheduled for the following configuration:

- long forebody
- zero degree angle of attack
- one MK 12/Mod 01 and two canted nozzle Recruits as sustainer
- two pushers, each equipped with four MK 07's.

The two (2) Recruit motors were added to the sustainer sled to provide sufficient power to attain the desired target velocity of 2800 fps. These modifications to the rocket sustainer section delayed the fourth firing until mid-January. Thus the last scheduled non-combustion ("Cold Flow") test was conducted on 17 January 1973.

For this run, the ramjet fuel supply system was filled and pressurized; however, ignition was not planned so the TEB igniter system was not installed. Fuel velocity was attained with the use of the two additional Recruit motors in parallel with the MK 12/Mod 01 sustainer motor. The ramjet fuel supply solenoid valve operated on schedule during the test run which provided design confirmation. However, fuel flow was not obtained since the fuel line had been capped.

Preliminary data showed a maximum velocity of 2821 fps with 3.8 seconds of time above Mach 2.3. The velocity profile for the test run is shown in Figure 20. The P_x/P_{t_o} static pressure ratios show that the inlets started just prior to reaching Mach 2.3 and were operating satisfactorily. Limited data are available from the SCP/LASRM freejet test to correlate inlet performance under cold flow, supercritical conditions. Also, since

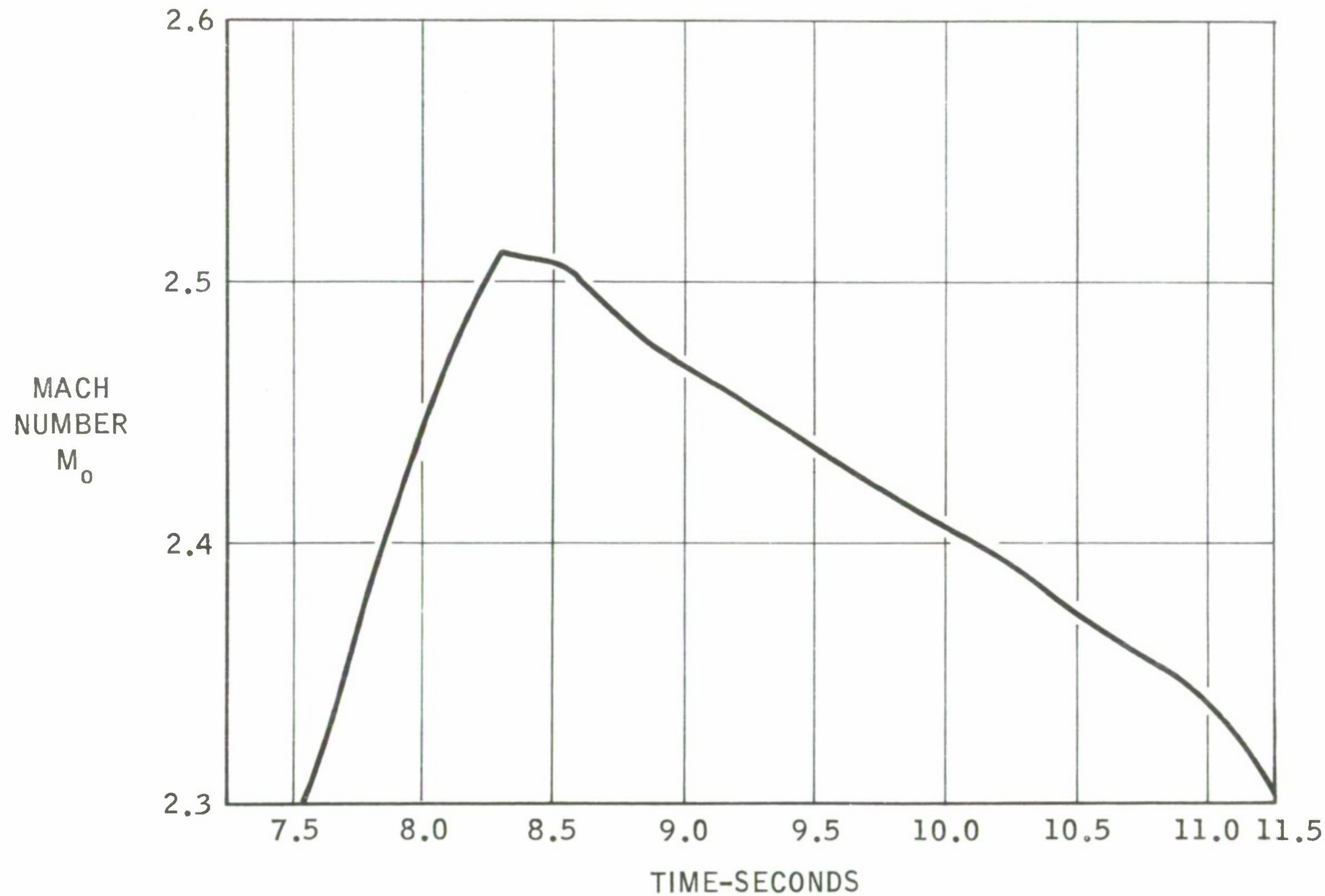


Figure 20. Trajectory Profile - Run 4 - Non-Combustion.

the splitter plates on the vehicle were parallel to the bodyline as opposed to a 1° cant angle, a precise correlation of inlet performance data was not anticipated. Sufficient agreement is shown in the comparative data shown in Table XI, Page 49 to confirm that the inlets started at the predicted Mach number and were operating satisfactorily throughout the velocity range of interest.

The first scheduled combustion ("hot flow") test was conducted on 16 February 1973. Prior to the test, the splitter plates were replaced and the new plates were installed at the 1° ramp angle. An electrical malfunction in the Conax squib valve prevented the TEB igniter from operating. Ignition was not obtained. The test did provide inlet cold flow data and confirmed the operability of all other subsystems. Inlet data obtained from the run are compared to available freejet test data in Table XI. The reasonable agreement between sled data and freejet data indicates the inlets to be started during the sled test and operating essentially at the same level as during freejet.

Maximum velocity for Run No. 5 was 2783 fps with 3.88 seconds of time above Mach 2.3. The velocity profile is shown in Figure 21.

An investigation of the Conax squib valve from Run No. 5 indicated a broken lead wire as the contributing factor to the malfunction. A review of those valves on hand at Marquardt for the remaining tests showed that the single strand electrical leads were very susceptible to breakage at the point of entry into the explosive valve housing. Careful potting of the wire with RTV at the entry to the housing, plus an overcover of tape and wire, provided sufficient rigidity to prevent breakage during handling.

The repetitive operation of the inlet system through the velocity transient from static to Mach 2.5 produced some structural problem with the inlets. The side plates locally yielded on each inlet in an area approximately one inch above the splitter plate. This yielding is probably due to the pressure differential created by a normal shock during the inlet "unstart" operation during acceleration and deceleration.

Dimensional measurements were made on the inlet before and after each run to maintain a check on the structural yielding. No cracks were visible in the sidewalls.

The second combustion ("hot flow") test was successfully conducted on 6 April 1973. The conditions and geometry for this run were a repeat of Run 5, since no combustion data were obtained on that run. Specifically, the conditions and geometry for the test are:

- Long forebody
- Zero degree angle of attach (0° α)
- MK 12/Mod 01 and two canted nozzle Recruit sustainers
- Two pushers each equipped with four MK 07's
- Target velocity 2800 fps.

TABLE XI. INLET DATA

Time	Mach No.	P_2/P_{TO} Sled	P_2/P_{TO} F/J	P_3/P_{TO} Sled	P_3/P_{TO} F/J	P_4/P_{TO} Sled	P_4/P_{TO} F/J	P_6/P_{TO} Sled	P_6/P_{TO} F/J	P_8/P_{TO} Sled	P_8/P_{TO} F/J
<u>Run No. 4</u>											
7.9	2.46	.30	.30-.33	.24	.28	.28	.36	.31	.28	.35	.36
8.2	2.51	.32	.36								
8.6	2.50	.31	.36								
10.1	2.40	.30	.30-.33	.27	.28	.30	.36	.33	.28	.36	.36
<u>Run No. 5</u>											
8.0	2.45	.19	.30-.33	.25	.28	.29	.36	.30	.28	.47	.36
8.5	2.51	.19	.36								
9.0	2.47	.17	.30	.26	.28	.29	.36	.29	.28	.47	.36
10.2	2.40	.20	.30-.33	.29	.28	.33	.36	.31	.28	.50	.36

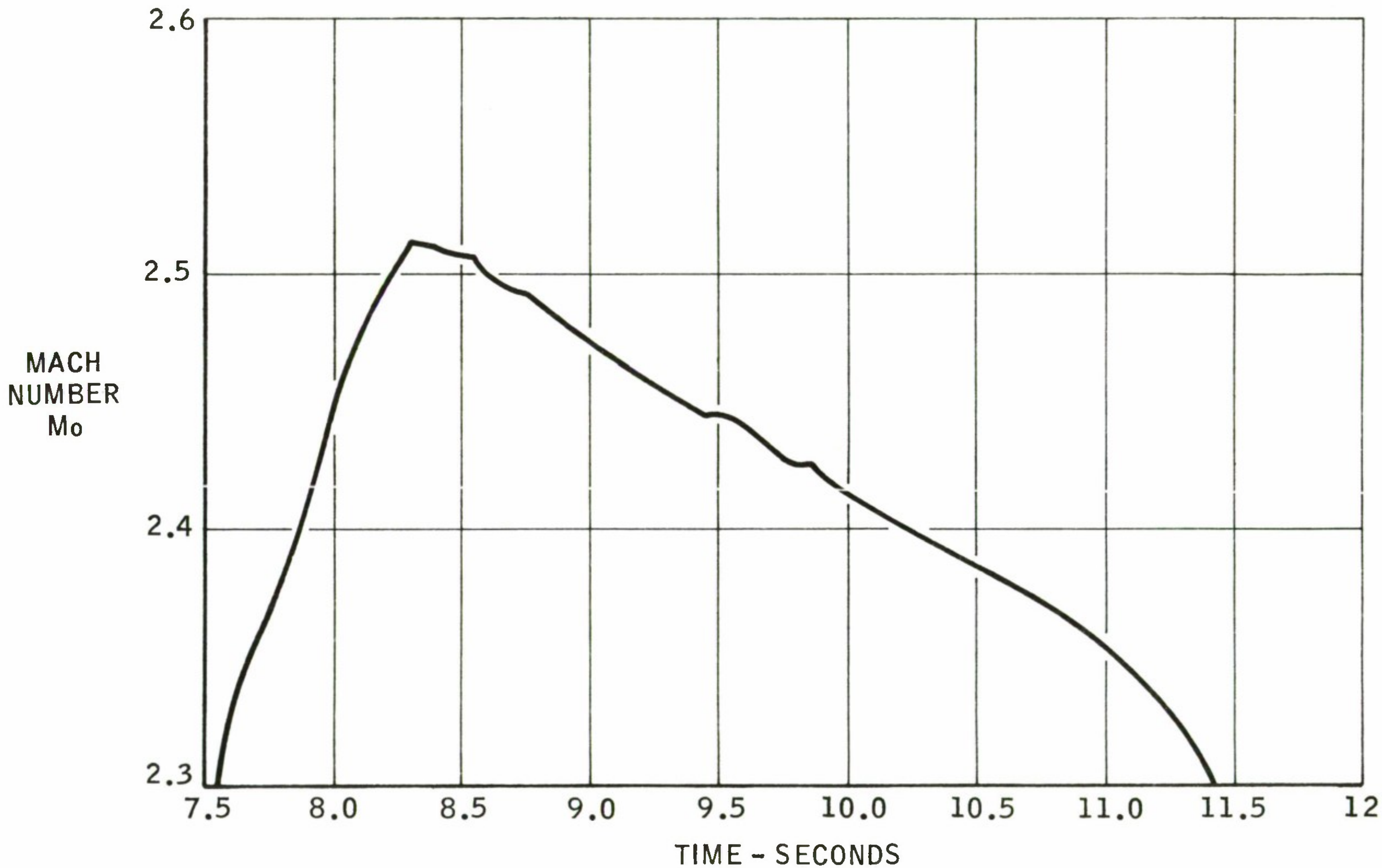


Figure 21. Trajectory Profile - Run 5 - Non-Combustion.

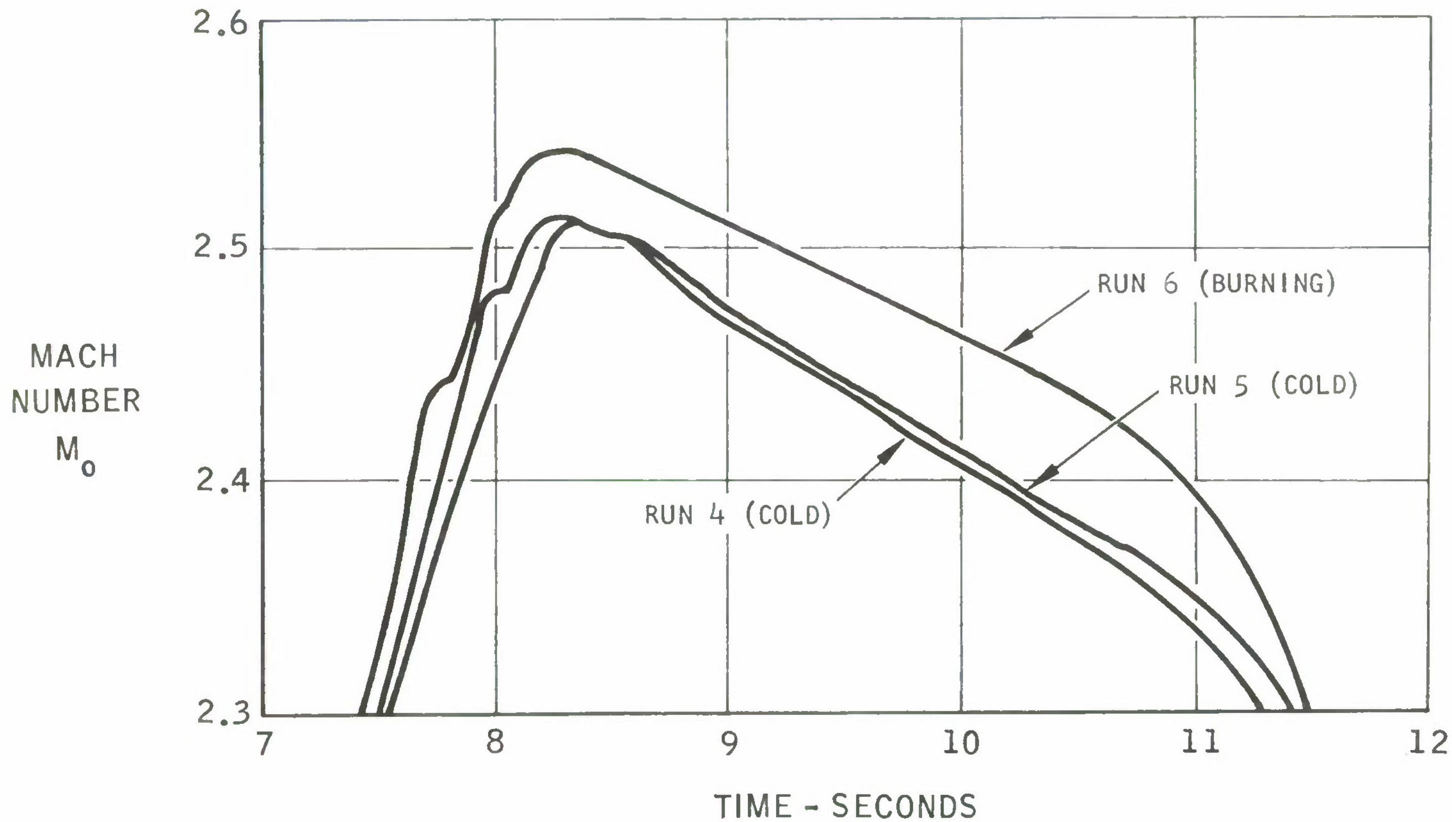


Figure 22. Velocity Profiles.

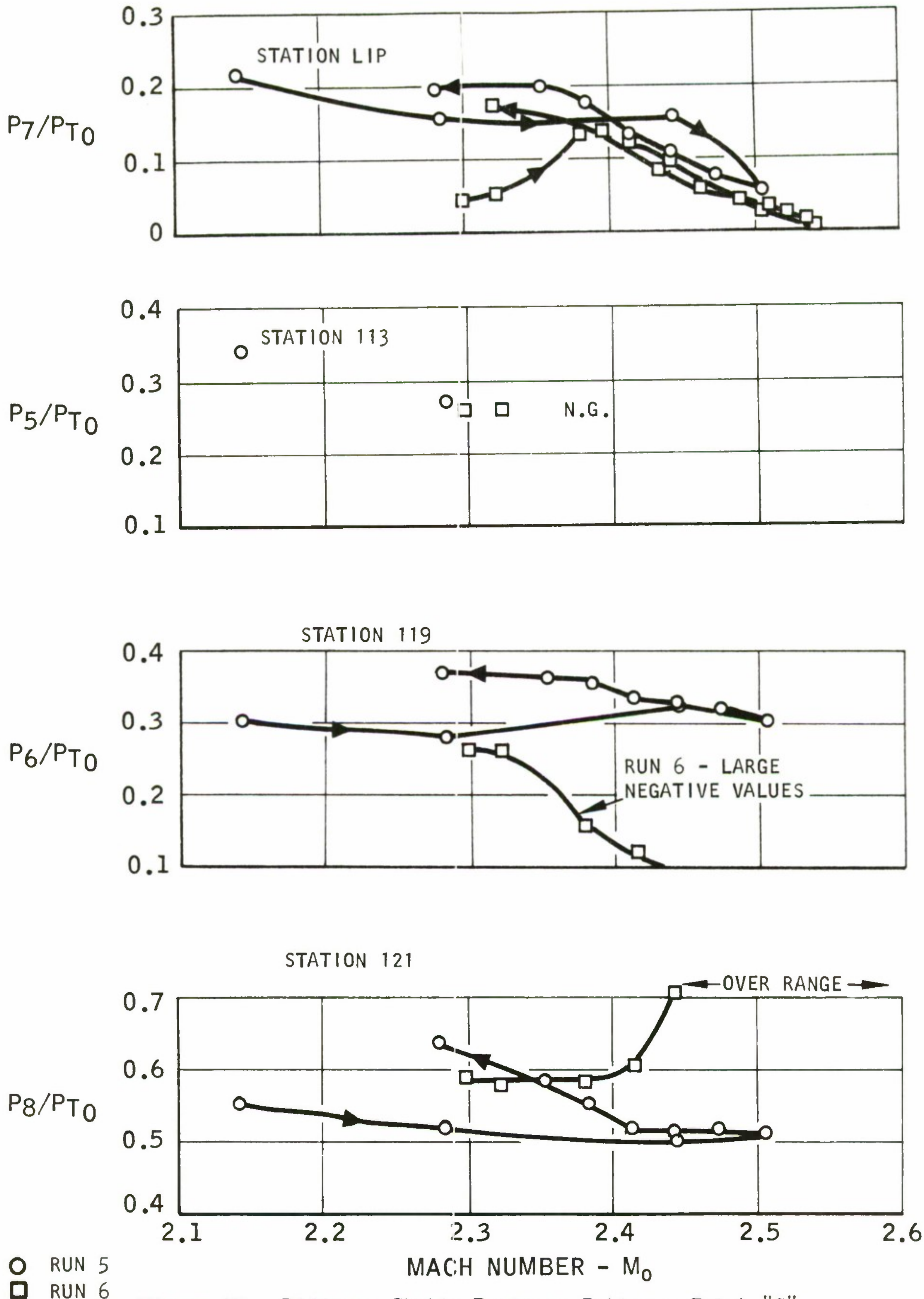


Figure 23. Diffuser Static Pressure Ratios - Inlet "C".

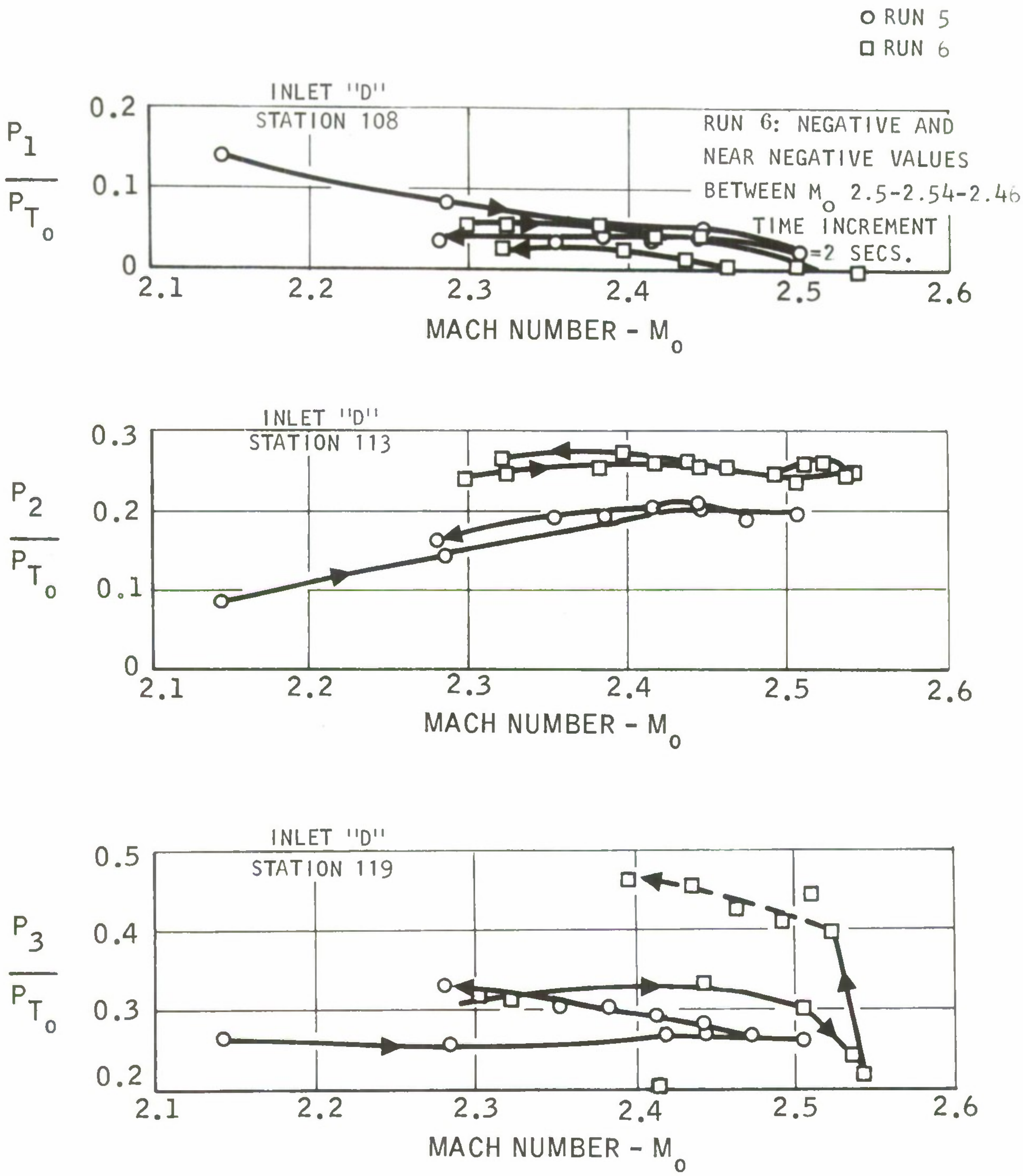


Figure 24. Diffuser Static Pressure Ratios - Inlet "D".

The velocity profile attained for the run is shown in Figure 22. A maximum velocity of 2826 fps was attained with 4.19 seconds above Mach 2.3 For comparison, the velocity profiles from the preceding non-combustion runs (Runs 4 and 5) are included in Figure 22.

Preliminary analyses from the "quick-look" oscillograph data indicated poor agreement between sled test performance and available data from the SCP/LASRM program. This was resolved to a large degree when digitized final data became available. A shift in the zero point for many of the data channels was evident in the digitized data. Correction for this zero shift brought reasonably good agreement between SCP/LASRM data and sled data. The zero degree angle of attack inlet performance for Runs 5 and 6 is shown in Figures 23 and 24.

P_{T_4}/P_{T_0} and A_0/A_c as a function of freestream Mach number are shown in Figure 25 for Run 5. Good comparison is obtained for engine total pressure recovery and capture area during the deceleration portion of the trajectory. This would indicate a reasonable similarity exists between the aerodynamics of sled testing and freejet blowdown testing. The inlet geometry, including the splitter plate ramp angle, were the same for both test modes.

An unexplained hysteresis is seen in the data as a function of the acceleration vs. deceleration side of the trajectory. The hysteresis effect is very evident in the capture area versus freestream Mach number data. A portion of the discrepancy between freejet and sled testing may be explained by data quality. Scale deflections were compressed to accommodate several channels of data per tape. However, there still appears to be an aerodynamic phenomena associated with the high acceleration rates. Some of the factors which can be postulated as occurring during this period are: (1) real time lag, (2) transducer sensitivity to acceleration, (3) acceleration effect on position of the shock train within the inlet, and (4) undetected weak shock systems across the inlets. Unfortunately, insufficient time and resources were available to investigate these parameters.

Inlet and total engine performance obtained during Run 6 are shown in Figure 26. Freejet and flight test data are shown for comparison. Fuel flow for Run 6 was set at $W_f = 1.184$ pps. This is slightly lower than the 1.2 pps used during the SCP/LASRM program. The lower fuel flow was used to guard against subcritical inlet performance at the lower Mach numbers. The fuel air ratios, F/A, obtained during the test were estimated to vary over the range 0.0184 to 0.0197. Target F/A for freejet and flight test was 0.02.

Engine performance, as reflected by the total pressure recovery across the system during ramjet operation shows a reasonable comparison with freejet tests. Particularly in light of the lower fuel-air ratios experienced in the sled test. Inlet performance, as measured by diffuser static pressure ratio, was somewhat lower than anticipated based upon freejet and flight test performance. Insufficient data is available to identify the reasons for the low inlet performance. However, the agreement on total engine performance is sufficiently close to confirm the test objective, e.g., utility of the sled test for airbreathing propulsion testing.

Run 6 concluded the program scope covered by this contract; however, further testing is scheduled by the Air Force Aero Propulsion Laboratory to obtain performance data at a negative 4° angle of attack.

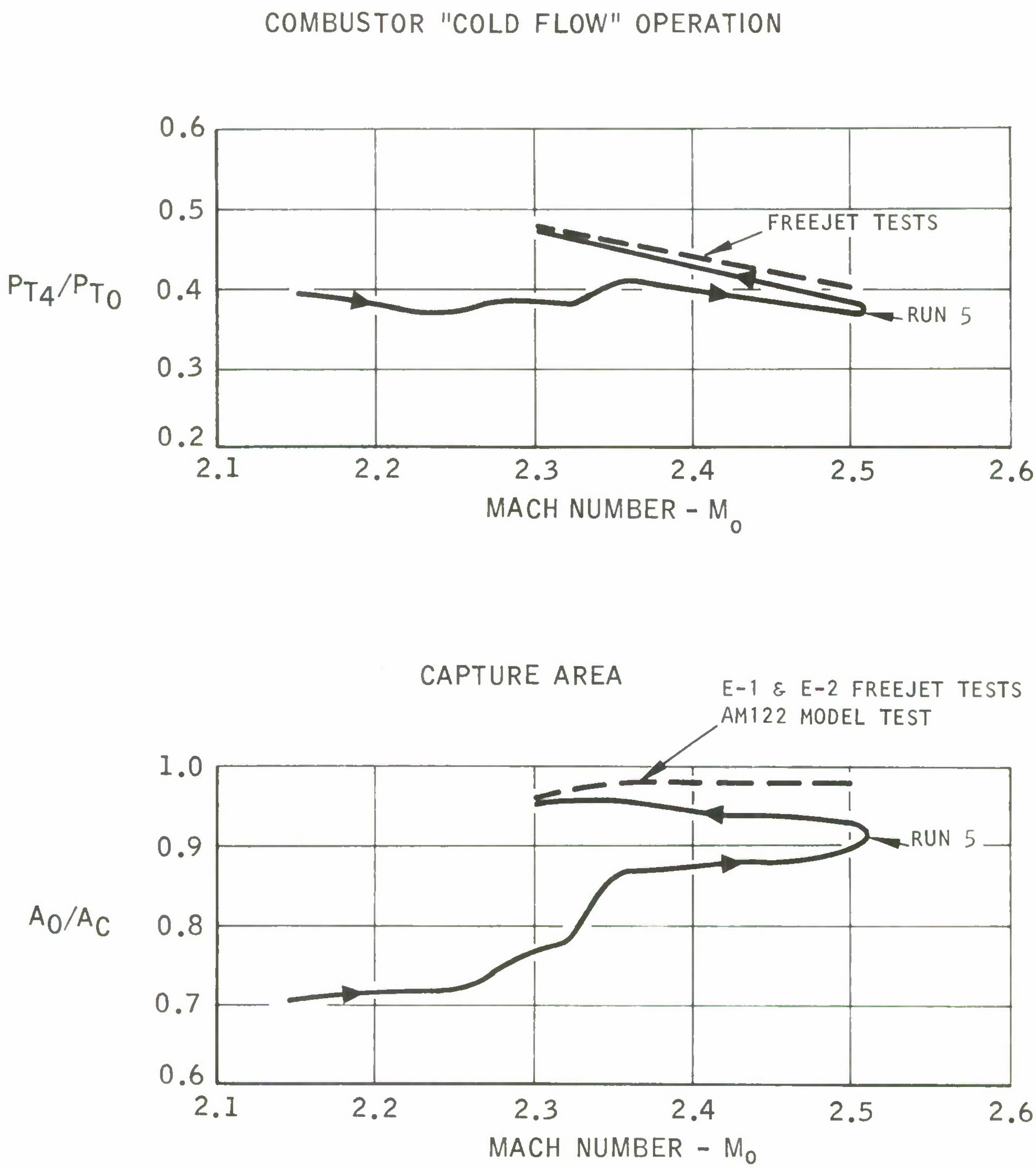
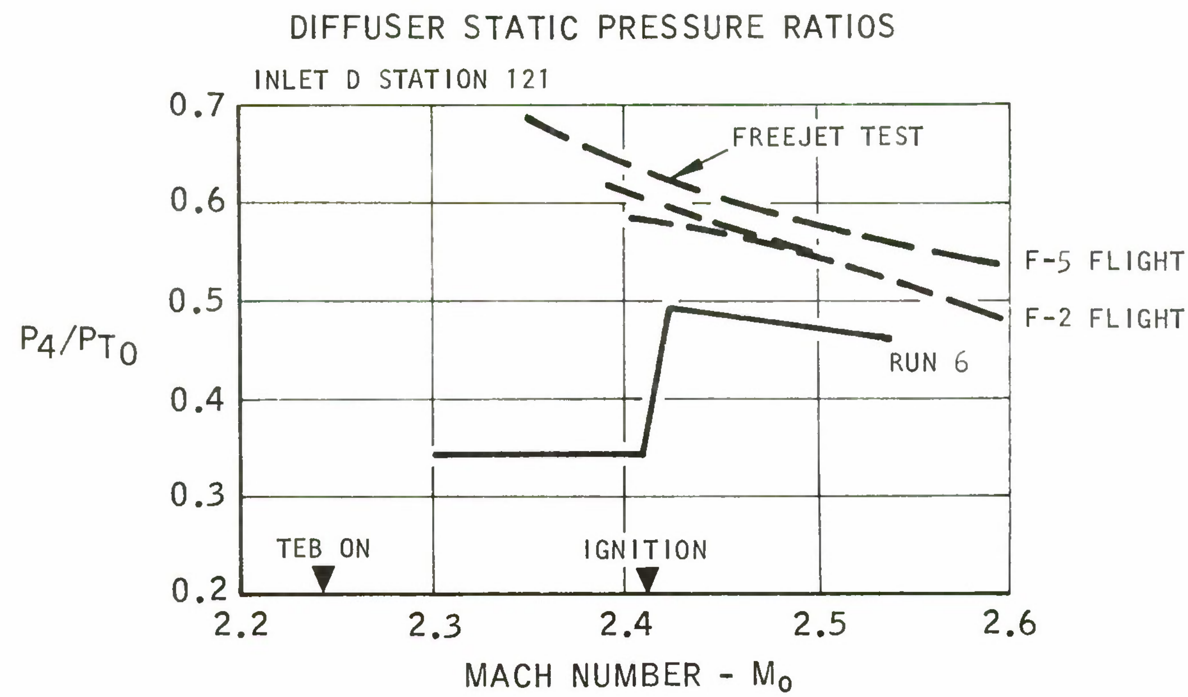


Figure 25. Cold Flow Sled Test Results.



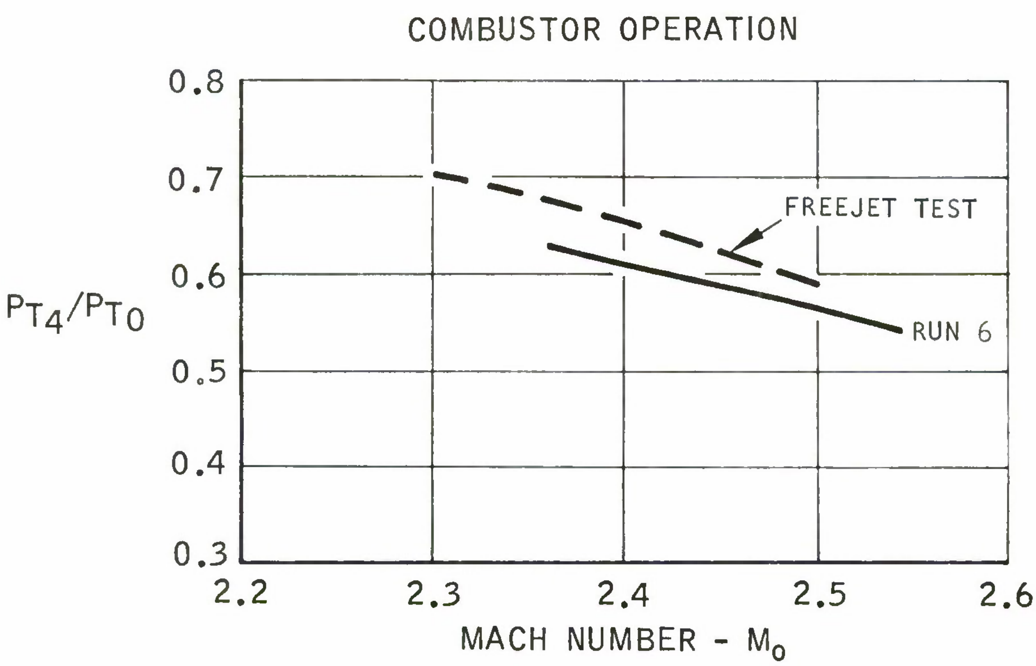


Figure 26. Combustion Sled Test Results.

SECTION V

OBSERVATIONS AND CONCLUSIONS

The following observations and conclusions are drawn from the studies, design exercises, and tests conducted in the program:

1. The SCP/LASRM flight test vehicle can be mounted on the available monorail sled in such a manner as to provide an interference free flow field at the inlets. This was indicated by aerodynamic studies conducted over the range of velocities and angles of attack of interest to this program. Confirmation was obtained by shadow graphs and inlet performance data obtained during test.

2. The predicted quasi-steady state and dynamic loads exceed the structural capability of the SCP/LASRM flight design. Design modifications incorporated into the hardware were adequate to provide positive structural margins in all critical components.

3. Four to five seconds of operation above the inlet design Mach number can be achieved on the 35, 000 ft. sled track. For the modified LASRM hardware and monorail sled, these test times were achieved with eight (8) MK7 Mod 0 booster motors for the pusher sleds and one (1) MK 12 Mod 1 plus two (2) Recruit motors for the sustainer sled.

4. The observed hysteresis of static pressure data as a function of acceleration/deceleration phenomena requires additional investigation. Several factors such as (1) real time lag, (2) transducer sensitivity to acceleration, and (3) acceleration effect on position of the shock train within the inlet can be postulated as being effective; however, insufficient data and resources are available for exploration of these factors.

The hysteresis could be a characteristic of inlet behavior under very high acceleration through a wide Mach number range (Mach 2.3 to 2.5 in 0.54 seconds). Should this be the case, there will be no comparison during flight test since these high acceleration rates will not be experienced under ramjet power only.

The following recommendations appear in order based upon the experience gained from this program:

1. The power density spectrum of a monorail sled is rather severe. Available data indicates considerable reduction of the power density with the use of a dual rail sled. The study of a specially designed dual rail propulsion test sled appears warranted to provide a less severe load environment for captive tests and/or flight test launching.

2. Where sled testing is contemplated as a possible means of performance evaluation or as a launch platform for flight testing, the loads environment for sled testing should be applied to the initial flight design. Whereas, the LASRM flight test hardware was successfully modified for this program, the structural changes were not compatible with a projected sled launch capability.

3. The capability of attaining ramjet thrust at flight velocities prior to release from the sled offers a good potential for low risk flight testing. Sufficient time is available on the sled trajectory to permit a performance checkoff prior to launch committment. Further studies of the use of the rocket boosted sled for ramjet propulsion flight testing should be undertaken.

APPENDIX A

PROPULSION SYSTEM SLED TEST
FUEL SYSTEM INSTALLATION AND REMOVAL

1.0 SCOPE

This specification establishes the requirements and procedures for the installation and removal of the Propulsion System Sled Test ramjet engine fuel system. Described herein, are the installation requirements, procedures, equipment, documentation, and safety instructions.

2.0 APPLICABLE DOCUMENTS, EQUIPMENT, AND MATERIAL

2.1 APPLICABILITY

The following documents of the issue (or if not specified the latest issued in effect) are a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, this specification shall take precedence.

2.2 DOCUMENTS

2.2.1 Government

2.2.2 The Marquardt Company

	Drawings
X28616	Engine Assembly, Propulsion Sled Test
X28621	Fuel Tank Assembly, Propulsion System Sled Test
X28620	Fuel System Assembly, Propulsion System Sled Test

2.3 EQUIPMENT

The following equipment is required to perform the fuel and igniter installation as specified herein and shown schematically in Figure 27.

2.3.1 Service and Checkout Equipment

Preloaded fuel system.

Nitrogen supply bottle.

3.0 GENERAL REQUIREMENTS

3.1 SAFETY

The safety requirements and procedures as specified herein, constitute the minimum safety requirements for operations involving flammable fluid handling and transfer operations. It shall be the responsibility of the Track Test Operations Chief to enforce all safety procedures and to coordinate with the cognizant Holloman AFB Safety Authority to ensure compliance with pertinent test site safety regulations. When additional safety requirements appear to be needed, but have not been provided, supplementary instructions shall be issued as required.

3.2 PERSONNEL

Personnel assigned responsibility for performing flammable fluid transfer and checkout operations as specified herein, shall be instructed in the nature of hazardous elements being worked with and the pertinent safety regulations governing the handling of such elements.

3.3 HANDLING AND STORAGE

Handling and storage of flammable fluids shall be in accordance with applicable regulations set forth by the cognizant Holloman AFB Safety Authority. Shelldyne fuel may be stored in any unprotected environment suitable for storage of kerosine type fuels.

Prior to performing Shelldyne loading operations, the fuel system shall be conditioned to a temperature of 60° and 80° Fahrenheit.

4.0 FUEL SYSTEM

4.1 GN_2 PRESSURE TANKS

1. Attach high pressure GN_2 supply line (commercial GN_2 bottle) to nitrogen pressure tanks at D-1. Close V-1 and V-5. Set GN_2 pressure regulator at 1020 psig. Slowly open V-1 and charge nitrogen pressure tanks. Close V-1.

Note: If nitrogen supply pressure exceeds setting on PRV-1, close off GN_2 supply. Open V-5 and vent GN_2 pressure tanks. After venting, close V-5 and V-1. Reset PRV-1 and GN_2 regulator. Slowly open V-1 and recharge pressure supply tanks.

2. Shut off GN_2 supply. Open V-5 to vent line from supply to V-1. Disconnect GN_2 supply at D-1.

4.2 FUEL SYSTEM INSTALLATION AND PRESSURE CHECK

Note: This check should be accomplished following any other check that has required disconnection of fuel system lines.

1. Replace the loaded fuel system equipment package into the sled fuel bay and securely fasten base plate to mounting brackets.

2. Connect D-1 to the nitrogen pressure tanks and D-2 to the fuel manifold. Close V-2. PRV-1 should be set for 1250 psig. Install pressure gage (0-1500 psig) at D-3.

3. Slowly open V-3, V-2 and V-1 to charge nitrogen side of fuel tank. Pressure check system by observing pressure gage reading at D-3 for 15 minutes. Check all connections and equipment on fuel side for leaks. If no leaks are observed, system can be considered charged and ready for service. Close V-3 and remove pressure gage from D-3.

Note: There shall no visible leakage at a tank pressure of 1000 ± 25 psig. Special attention should be paid to any connections that may have been disturbed during previous checkouts.

4.3 FUEL SYSTEM REMOVAL

1. Disconnect electrical power from solenoid valve.

2. Vent nitrogen side of fuel tank by slowly opening V-3. When pressure drops to ambient, fuel system equipment can be disconnected from nitrogen pressure at D-1 and from fuel manifold at D-2. Close V-2 and V-3.

Note: GN_2 pressure tanks are to remain unpressurized at all times during storage and service between test runs.

3. Disconnect P_{F_T} and P_{F_M} transducer.

4. Remove fuel system equipment from sled fuel bay.

5. Place fuel system (less N_2 pressure tanks) in shipping container for return to The Marquardt Company, Van Nuys, California.

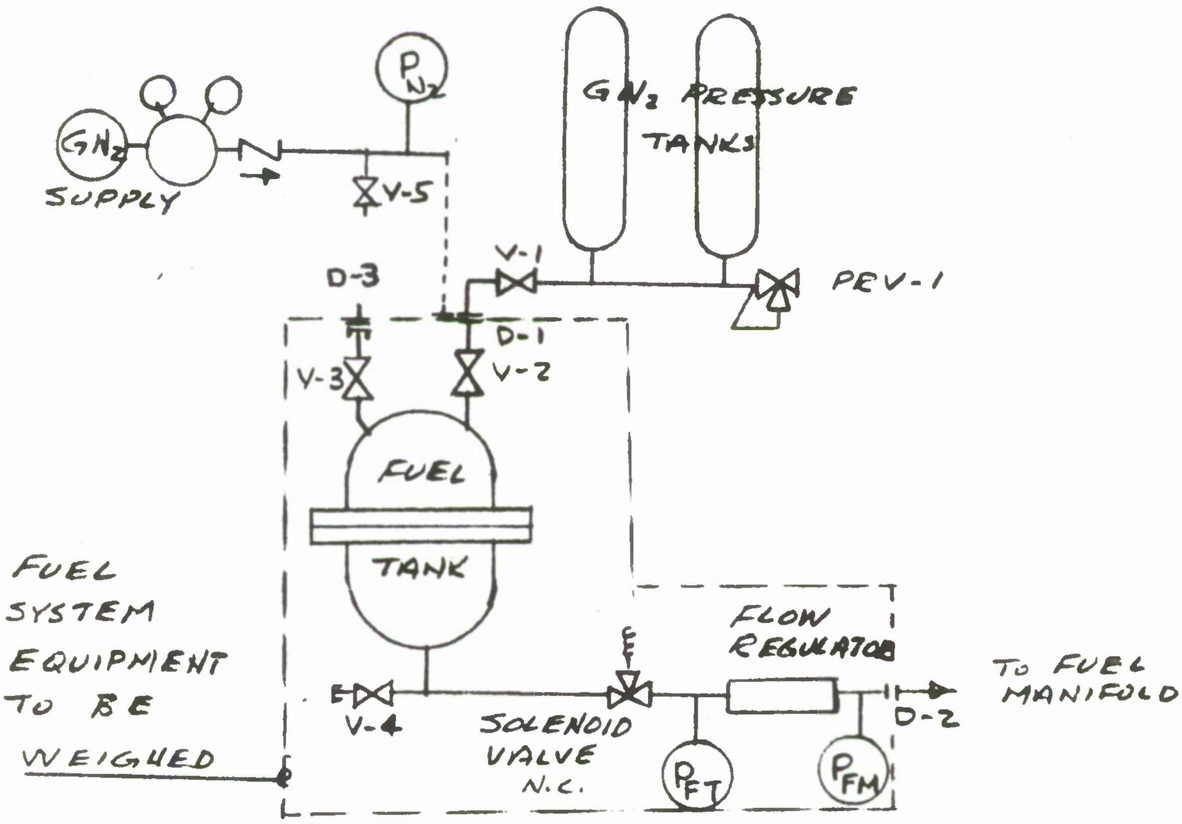


Figure 27. Fuel System Schematic

APPENDIX B

PROPULSION SYSTEM SLED TEST IGNITER SYSTEM INSTALLATION AND REMOVAL

1.0 SCOPE

This specification establishes the requirements and procedures for the installation and removal of the Propulsion System Sled Test ramjet engine igniter system. Described herein, are the service and checkout requirements, procedures, equipment, documentation, and safety instructions.

2.0 APPLICABLE DOCUMENTS, EQUIPMENT, AND MATERIAL

2.1 APPLICABILITY

The following documents of the issue (or if not specified the latest issued in effect) are a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, this specification shall take precedence.

2.2 DOCUMENTS

2.2.1 Government

2.2.2 The Marquardt Company

	Procedures
TDP 4513	Triethylborane a Pyrotechnic Highly Reactive Fuel
	Drawings
X28616	Engine Assembly, Propulsion Sled Test
X22892	Triethylborane Tank Assembly
X22894	Igniter Assembly (ramjet)

2.3 EQUIPMENT

The following equipment is required to perform the igniter installation and removal as specified herein and shown schematically in Figure 28.

2.3.1 Service and Checkout Equipment

Pre-loaded TEB Igniter System

N_2 pressure supply

TEB Off-load equipment

2.3.2 Safety Equipment

Apron, Flame Resistant	-Fyrepel #9750/SL
Gloves, vinyl coated	-MSA #CR34334
Hood, Flame Resistant	-Fyrepel #9150 0/9

3.0 GENERAL REQUIREMENTS

3.1 PROPERTIES

Triethylborane is a flammable liquid and is a dangerous fire hazard. It is self-igniting upon exposure to normal atmospheric conditions.

3.2 SAFETY

The safety requirements and procedures as specified herein, constitute the minimum safety requirements for operations involving flammable fluid handling and transfer operations. It shall be the responsibility of the Track Test Operations Chief to enforce all safety procedures and to coordinate with the cognizant Holloman AFB Safety Authority to ensure compliance with pertinent test site safety regulations. When additional safety requirements appear to be needed, but have not been provided, supplementary instructions shall be issued as required.

3.3 PERSONNEL

Personnel assigned responsibility for performing flammable fluid transfer and checkout operations as specified herein, shall be instructed in the nature of hazardous elements being worked with and the pertinent safety regulations governing the handling of such elements. All personnel required to perform operations in accordance with this specification shall have passed a special fuels physical examination and shall maintain a current medical examination record while performing this operation.

3.3 HANDLING AND STORAGE

Handling and storage of flammable fluids shall be in accordance with applicable regulations set forth by the cognizant Holloman AFB Safety Authority. Triethylborane shall be stored in a hazardous fuels area. It's container may be exposed to the ambient environment.

Store in a cool, well ventilated area away from fire hazards. Keep containers tightly closed.

3.4 RECORDS

Pertinent data as specified herein shall be maintained relative to the storage, loading, and checkout of fuels, and shall be entered into the propulsion system log sheet.

3.5 ABBREVIATIONS

Abbreviations used in this specification are defined in Table XII.

TABLE XII . LIST OF ABBREVIATIONS

TEB	Triethylborane
GN_2	Gaseous Nitrogen
PSIG	Pressure, Pounds per Square Inch Gauge
D-1	Disconnect Point
V-1	Hand Value
PRV	Pressure Relief Valve
N.C.	Normally closed
P-S	Supply Pressure
P-V	Vacuum Pump Pressure
P-T	Fuel Supply Tank Pressure

4.0 IGNITER PRESSURANT LOADING

4.1 PERSONNEL SAFETY EQUIPMENT

Personnel pressurizing and installing the ramjet igniter shall be dressed in the following safety apparel before commencing operations involving transfer or handling of triethylborane.

a. Apron, flame resistant - Fyrepel #9750/SL
b. Hood, flame resistant - Fyrepel #9150 0/9
c. Gloves, vinyl coated -MSA #CF34335

WARNING: Extreme care must be exercised in transferring the handling of Triethylborane. When loaded, the igniter is a pressurized vessel containing a toxic, highly flammable, pyrophoric fluid which is isolated by a normally closed pyrotechnic valve. Failure to wear required apparel and to comply with safety warnings could result in serious injury to personnel.

4.2 PRESSURANT LOADING OPERATION

Pressurant shall not be loaded into igniter bottle unless TEB has been previously loaded. Pressurant loading shall be delayed as long as possible without jeopardizing test schedule.

1. Install loaded igniter bottle in the Pressurant Loading Service equipment in accordance with Figure 28.

2. Insure that valves N-1 and N-2 are closed.

3. Set the GN_2 regulator pressure to 325 psig and slowly open valve N-2. Regulate N-2 flow into igniter with N-2 until P-1 pressure is 320 to 325 psig.

   CAUTION: Observe TEB side of bottle for evidence of leakage. Dump pressure immediately if leak occurs.

4. When pressure P-1 is stable close valve N-2.

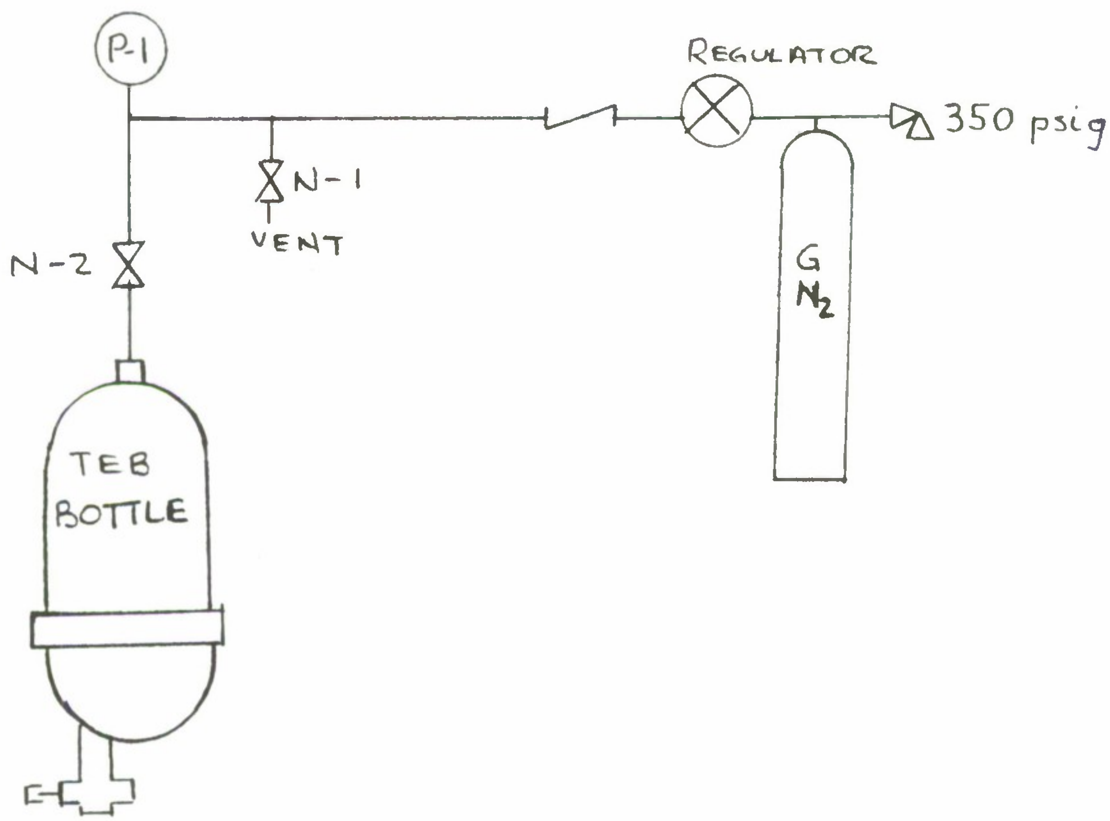


Figure 28. Pressure Test Fixture Schematic

4.3 TEB LEAKAGE CHECK

1. Visually inspect the igniter bottle gasket areas, capped TEB fill valve, and uncapped TEB discharge port for evidence of high pressure TEB leakage. Leakage will be evident by burning at the point of leakage.

2. When TEB leakage check is satisfactory, vent the P-1 pressure to 200 psig by opening valve N-1. Reseat the GN_2 service port check valve and repeat steps 3 and 4 of Section 4.2.

3. When leakage check is complete, vent system pressure by reducing regulator setting to zero and opening valve N-1.

   WARNING: If leakage is evident, immediately depressurize the igniter, off-load the TEB, per Section 4.5 . If leakage is prolonged, explosive failure of the igniter bottle and/or pyrotechnic valve may occur.

5. No TEB leakage is allowable.

6. Remove the igniter from the TEB pressurizing equipment. Reinstall the TEB GN_2 port safety cap.

   WARNING: Handle the pressurized and loaded igniter with extreme care. Careless handling could cause rupture of the bottle, resulting in serious injury or death to personnel.

4.4 PRESSURANT LEAKAGE CHECK

1. Submerge all but the igniter pyrotechnic valve and electrical connections in a container of water.

2. No GN_2 leakage is allowable.

3. If no leakage is evident, the igniter is ready for installation in the test engine.

4.5 OFFLOAD AND FLUSH

Igniter Bottle Pressurant and TEB shall be off-loaded as follows:

CAUTION: Pressurant must be off-loaded before uncapping TEB service port check valve.

4.6 PRESSURANT OFF-LOADING

1. Install loaded igniter bottle in the TEB off-loading equipment in accordance with Figure 29. Do not connect any fittings to the TEB service check valve port.

2. Insure that valve N-1, N-2 and N-3 are closed

3. Increase GN_2 regulator pressure to 320 psig and slowly open valve N-2 until P-1 pressure is 300 to 310 psig. Unseat the GN_2 service port check valve. Vent the bottle pressure to 30 psig as indicated on P-1 by opening valve N-1.

4. Close valve N-2

4.7 TEB-OFF-LOADING

1. Complete installation of igniter bottle in the TEB off-loading equipment in accordance with Figure 29 by connecting remaining lines to TEB service port.

   CAUTION: A small quantity of TEB will be present under the TEB service port check valve cap.

2. Purge the TEB service port connection with GN_2 by setting the regulator to 30 psig and opening valves N-6 and N-5.

3. Pressure check TEB service port connection by closing valve N-5. Open valve N-2. Observe pressure gauge P-1 for evidence of leakage.

4. If leak check is satisfactory, close valve N-6 and N-2, open valve N-5 and slowly unseat TEB service port check valve. Slowly open valve N-2, observing waste tank for evidence of TEB flow. When flow has stopped, close valve N-5 and N-2.

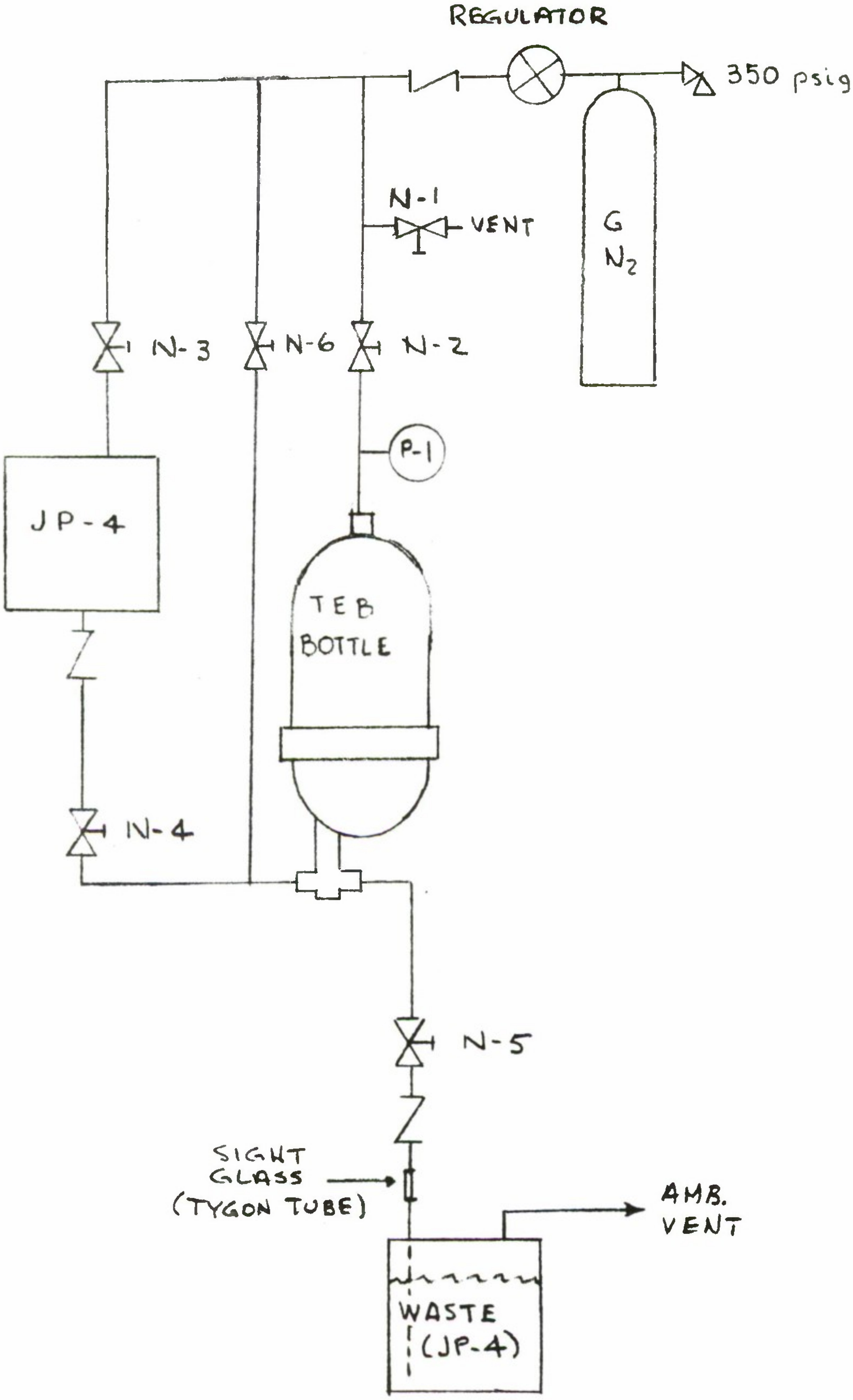


Figure 29. TEB Off-Loading Equipment

4.8 IGNITER BOTTLE FLUSH (Must follow TEB off-loading Section 4.7)

1. Pressurize the JP-4 tank by opening valve N-3.

2. Open valves N-4 and N-5 until JP-4 is observed at waste tank. Then close valve N-5. Load JP-4 into the igniter bottle by opening N-1 and N-2 to vent the gas side of the bottle bladder during filling.

3. When bottle is full, close valves N-4, N-1 and N-3 and open valve N-2. Purge JP-4 from the bottle by opening valve N-5 to dump JP-4 in the waste tank. Close N-5 when dump flow has stopped. Close valve N-2.

4. Repeat flush cycle at least twice then vent JP-4 tank by closing valves N-6 and N-2, opening valve N-3 and N-1. Close N-3 when tank is vented.

5. Purge JP-4 from service connection by opening valves N-5 and N-6 until JP-4 and is no longer observe at waste tank.

6. When flush process has been completed close valves N-5 and N-6. Open valves N-2 and N-1 to bleed GN_2 system pressure to zero.

7. Close all system valves including the unseated service port check valves and remove the igniter bottle from the service equipment.

5.0 IGNITER STORAGE

5.1 HANDLING CONTAINER

1. Place the igniter in the igniter service magazine.

2. Ground the igniter squib leads and the igniter bottle and install the magazine cover.

5.2 STORAGE AREA

1. Move the igniter in its service magazine to the area identified for hazardous storage.

NOTE: No more than one (1) igniter assembly shall be stored in the hazardous storage area at any one time.

APPENDIX C

CALCULATION OF CAPTURE AREA RATIO FOR COLD FLOW SLED TEST

1. Continuity between freestream Station ∞ and nozzle throat Station 5:

$$\frac{\left(P/P_t\, \mathring{m}_\infty\right)\left(A_\infty/A_c\right)\left(A_c/A_3\right)\, P_{t\infty}}{\sqrt{T_{T\infty}}} = \frac{\left(P/P_t\, \mathring{m}_5\right)\left(A_5/A_3\right)\left(P_{t5}\right)\left(C_{nm}\right)}{\sqrt{T_{T5}}}$$

$$\frac{A_\infty}{A_c} = \left(\frac{P/P_t\, \mathring{m}_5}{P/P_t\, \mathring{m}_\infty}\right)\left(\frac{A_5/A_3}{A_c/A_3}\right)\left(\frac{P_{t5}}{P_{t\infty}}\right)\left(C_{NM}\right)\left(\frac{\sqrt{T_{T\infty}}}{\sqrt{T_{T5}}}\right)$$

Where: $C_{NM} = 0.965$

$T_{T\infty} = T_{T5}$ No Heat Addition

A_5 measured $= 51.424$ sq. inches

A_3 reference area $= 177$ sq. inches

$A_5/A_3 = 0.291$

A_c measured $= 52.497$ sq. inches

$A_c/A_3 = 0.30$

$P_{t5} = P_{t4}$ isentropic assumed

$$P_{t4} = \frac{P_9}{\left(P/P_t\right)_{chamber}}$$

where: M_4 is determined from A/A^*

P_9 = measured static in plenum chamber just upstream of Throat (Sta. 4)

where: A/A^* throat $= 1.0$

$A^* = (A_5)\,(C_{NM})$

$$(A/A^*)_4 = \frac{A\ chamber}{A^*}$$

$$A_{chamber} = \left(15''\ \text{dia} - 2\,(0.070)\right)^2 \frac{\pi}{4}$$

$= 173.43$ sq. inches

$$(A/A^*)_4 = \frac{173.43}{(51.424)\,(.965)} = 3.494$$

$M_4 = 0.169$

$P/P_{t4} = 0.98$

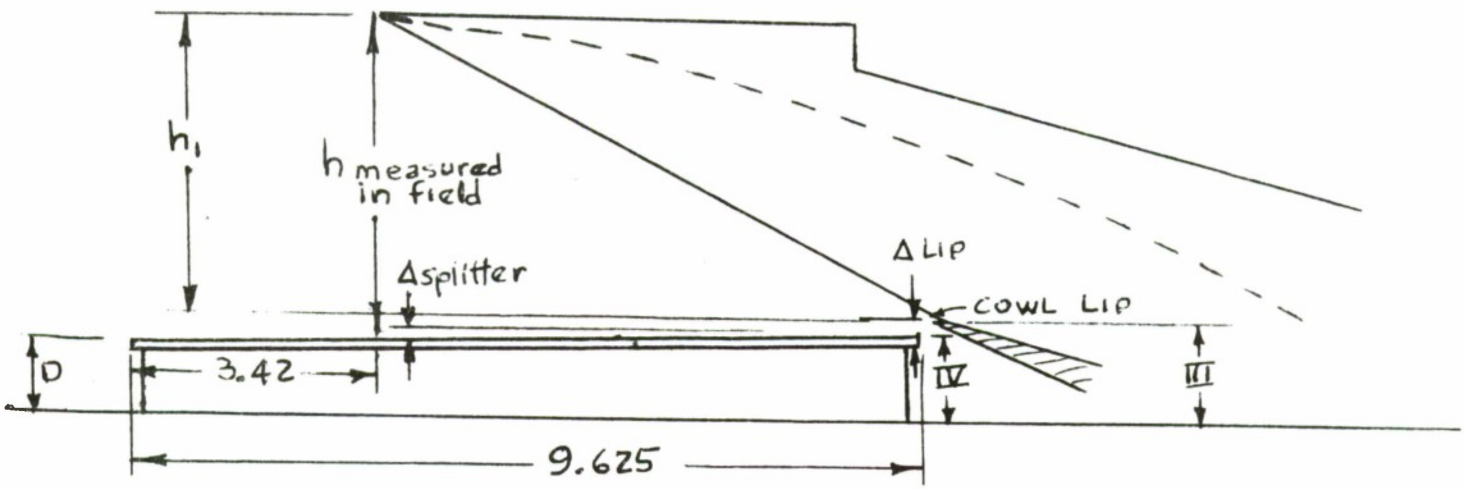
$$P_{t_4} = P_9/0.980$$

$$P_{T_\infty} = \frac{P_{amb}}{P/P_{t_\infty}} \quad \therefore \quad P/P_{t_\infty} = f\,(M_\infty)$$

$$(P/P_t\ \mathring{m})_5 = f\,(M_5) = \text{choked throat } M = 1.0$$

$$(P/P_t\ \mathring{m})_\infty = f\,(M_\infty)$$

$$A_C = A_{C_D} + A_{C_C} + A_{C_B} + A_{C_A} \ \therefore\ A_C = (h_1 \times W)\,4$$



W = Average $W_{measured}$ at a, b, c for each inlet

h1 = h measured - Δ splitter - Δ lip for each inlet

$\Delta_{splitter}$ based on 1° cant angle = 0.017"

Δ_{lip} = inboard lip height (III) - splitter plate height (IV)

	Inlet D	Inlet C	Inlet B	Inlet A
W_{avg}	3.725	3.713	3.701	3.725
$h_{1\ avg}$	3.560	3.499	3.514	3.555

APPENDIX D

STRESS ANALYSIS - LASRM SLED TEST ENGINE MOUNTS

INTRODUCTION

The attached stress analysis was made to satisfy the structural requirements of AF Contract F33615-71-C-1372. Loads were specified by North American-Rockwell for the two mounting stations and the payload, as shown in pages 81 to 83 of the attached analysis.

The loads are based on the reactions of the payload to the imposed vibration and accelerations from the rocket powered sled and associated track during the test runs. The loads and reactions at the mounting points were all assumed to act simultaneously and during ramjet operation.

Because of the short run duration, maximum temperatures of the mounts and adjacent structure was assumed to be 300^{o}F.

SUMMARY OF RESULTS

The results of the stress analysis are shown in Table XIII Margins of Safety, Page 80. The sled test engine and mounts are considered satisfactory for the structural requirements.

DISCUSSION

The stress analysis was performed as follows:

Sta. 124.4 - The load cell at station 124.4 was considered to be pinned with respect to axial loads, and rigid for lateral loads. Consequently, the axial reaction to the payload caused a pitching moment at the centerline of the payload at station 124.4. The lateral load from the payload caused a moment at the load cell equal to the shear transfer less roll inertia. The lateral moment is further reduced by the assumed lateral moment distribution between the forward and aft load cells.

It was assumed that 70% of the total torque about the centerline of the load cells would be reacted by the forward load cell and 30% by the aft load cell. This assumption, although arbitrary, should result in conservative loading of the mount at station 124.4.

The analysis of the mount frame at the station 124.4 was simplified by the assumption of inflection points. Because of the rapid change in section properties at the frame leg junction with the payload flange rings and approximately equal I/L of the base plus load cell and the ring flanges, the inflection point would most likely be at frame leg junction with the ring flanges.

The inflection points were assumed for the loading resulting from the lateral and vertical loads only. The axial loads are transferred from the centerline of the load cell directly to the payload centerline causing a linear variation in moments up the frame from the load cell.

Plastic bending effects were used to increase the equivalent bending stress allowables where applicable. It was considered that even though the random vibration contributes somewhat more than one-half the design limit loads, the plastic bending increase is equivalent to the allowable stress for very rapid strain rates.

The bolts connecting the various flange rings and the mount frame of the station 124.4 were analyzed for the combined tension and shear loads resulting from the body bending moments and the frame shear loads. It was conservatively assumed that not all the flange bolts were effective in resisting shear. Actually, the mount frame helps to distribute the shear since it pilots the body rings.

Sta. 130 - The tailpipe was analyzed for the shear and bending caused by the reactions at station 160.4 in combination with the ramjet pressures.

Sta. 160.4 - In addition to the loads specified by North American-Rockwell, the mount of station 160.4 must accommodate a thermal expansion of the tailpipe calculated to be ± .15 inches. This was accomplished by treating the thin plate as a flexure fixed at the top and bottom.

An equation was developed expressing the maximum combined stress in terms of "t" for the flexure. This equation was differentiated and set to zero to obtain the minimum stress as a function of "t". The second equation was then solved for the value of "t" that would satisfy the equation. The calculated optimum value of "t" was a little bit greater than an available stock size of .125 inches. The smaller value of .125 in. was then used to obtain the least value of axial load on the tailpipe due to flexure loads.

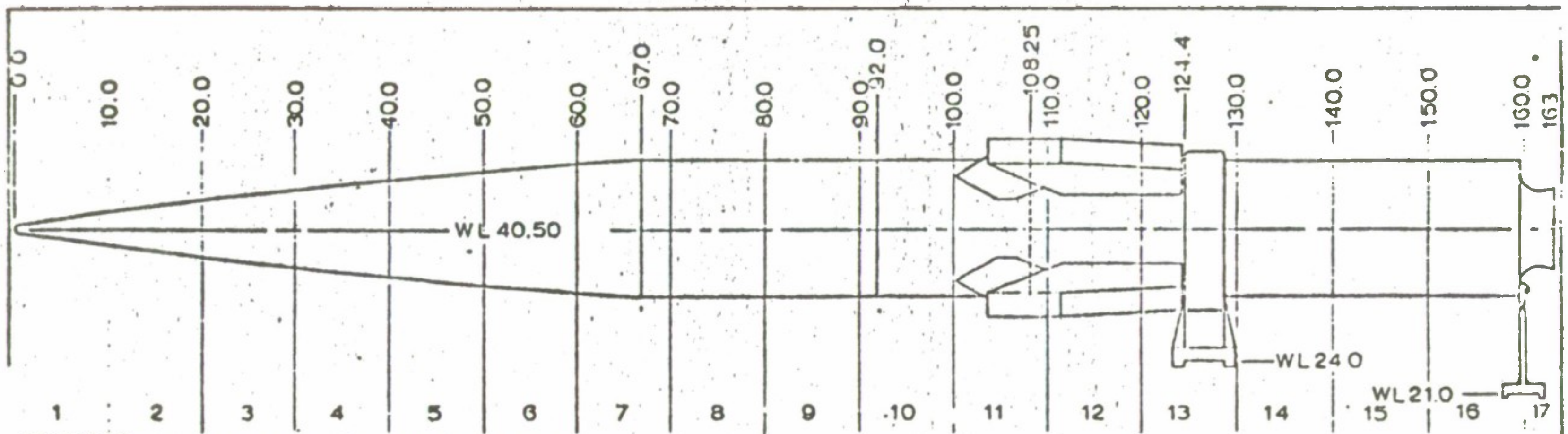
Because half the vertical load of station 160.4 is due to quasi-steady loads, the flexure plate was analyzed for column buckling combined with bending. Margins were conservatively obtained by combining column stresses with maximum bending stresses at the fixed ends. The flexure is a beam column, but since the fixed ends and the inflection point will not deflect axially as a result of load, no secondary bending will develop.

The loads and stresses on the base attachment bolts were low.

TABLE XIII. MARGINS OF SAFETY

PART NAME	PART NUMBER	REMARKS	STRESS (KSI) OR LOADS	MARGINS OF SAFETY	PAGE No.
STA. 124.4	MOUNT	AT INFLECTION POINT	109	.15	2.4
	FRAME ATTACH BOLTS	AT ℄ PAYLOAD	88	.10	2.8
	RINGS	COMBINED RINGS IN BENDING	6.5	LARGE	2.14
	321 CRES FLANGE	BENDING AT WELD	16.66	.62	2.16
	DOUBLER	TENSION ON DOUBLER AT WELD	47.4	34	2.18
	BASE	BENDING AT BOLT HOLES WITH 1.75 K_T	144.0	0.05	2.19
	SHEAR PINS IN BASE	3 PINS ONLY 1.5 ULT. FACTOR	68.5	.37	2.21
STA. 130.0	TAIL PIPE	BENDING PLUS INTERNAL PRESSURE	45.8	LARGE	2.24
STA. 160.4	FLEXURE	COMBINED BENDING PLUS COMPRESS. AT BASE 1.25 ULT. FACTOR	$R(b+c)=$ .972	.03	3.3
	BOLTS TO LOAD CELL	MAX. TENSION LOAD TO BOLT. 1.5 ULT. FACTOR	4.75	LARGE	3.4
	BASE	BENDING ON BASE FROM BOLT LOAD	38.1	LARGE	3.5
STA. 109	DOUBLER	BENDING AND TENSION IN DOUBLER	39.7	.77	2.22

TABLE XIV. PAYLOAD DEFINITION



REMARKS: Attach fittings to be revised -- moved upward.
Weights and inertias will change in sections 13, 16 and 17.

SECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
W.T.	4.431	11.867	11.217	8.370	9.240	9.940	35.853	19.020	13.247	35.158	23.704	58.55[illegible]	349.44	12.440	12.44	49.856	50.522
$\bar{X}$	6.638	15.390	24.557	35.379	47.163	52.990	67.154	73.667	85.00	93.585	105.447	115.416	125.137	135.00	145.00	158.413	160.[illegible]
$\bar{Y}$	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
$\bar{Z}$	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	40.50	31.[illegible]	40.50	40.50	26.800	30.500
Ixx	6.58	71.66	119.66	172.82	298.04	368.85	1743.81	999.80	735.28	1756.19	830.60	3520.32	29855.10	684.89	684.89	4479.00	8415.60
iyy	43.36	133.63	120.21	121.08	235.06	288.66	1029.03	689.73	478.04	1051.32	565.51	1760.20	23040.30	342.50	342.50	3890.90	8206.40
izz	43.36	133.63	120.21	121.08	235.06	218.66	1029.03	689.73	478.04	1051.32	565.51	1760.20	14927.50	342.50	342.50	2239.50	4207.80

TOTAL WT	$\bar{X}$	$\bar{Y}$	$\bar{Z}$	ixx	Iyy	Izz	Ixz	
715.296	115.278	-0-	34.532	15.29	183.51	177.06	-17.81	Slug Ft^2

HI SPEED PILOT PROP. TEST SLED PAYLOAD WEIGHTS & MASS PROPERTIES DATA

J. A. Riehle   10-29-71

SM322
ENCLOSURE (2) to
72CL 10443

TABLE XV. LIMIT DESIGN LOADS PAYLOAD

PAYLOAD - STATION	SHEAR - LB.		BENDING IN - LB.	
	LATERAL	VERTICAL	YAWING	PITCHING
6.648000	412	641	0	0
15.39000	1188	1840	3611	5743
24.55700	1609	2494	14495	22770
35.37900	1689	2638	31903	50017
47.16300	1580	2497	51786	81433
52.99000	1401	2221	60968	96000
67.15400	660	1348	80658	127924
73.66700	688	1901	83485	132277
85.00000	900	2583	83012	131793
93.68600	1631	4314	80325	128193
105.4470	2057	5503	69348	119436
115.4160	2821	7908	60051	126791
125.1370	5569	19886	53953	168131
126.3999	5569] 7,073	19979] 36,470	52725	184832
126.3999	1503	16492	52725	* 489829
135.0000	1541	16248	39825	363310
145.0000	1574	16086	24479	219159
158.4130	1887	15966	3603	28181
160.4000	1887] 2,823	15916] 17,403	290	443
160.4000	936	1487	290	443
160.6980	0	0	0	0

* Based on ¢ transducers 12 in. below ¢ Payload.

SM332

ENCLOSURE (3) to
72CL 10443

TABLE XVI. LIMIT DESIGN LOADS ~ LOAD CELLS

PAYLOAD STATION	ITEM		UNITS	RANDOM LOADS		RANDOM LIMIT LOADS	QUASI-STEADY LOADS	DESIGN LIMIT LOADS
				CORRELATED	UNCORRELATED			
6.64	Deflection		In.	0.096	0.093	0.789		
126.4	Axial Force		Lb.	6,770	5,630	12,400	14,000	26,400
	Lateral Force		Lb.	2,860	2,690	5,550	0	5,550
	Vertical Force		Lb.	12,650	12,200	24,850	8,300	33,750
	Bending Moments*	Pitching	In. Lb.	732,000	118,000	250,000	240,000	490,000*
		Yawing	In. Lb.	30,600	22,800	53,400	0	53,400*
16C.4	Lateral Force		Lb.	1,330	1,190	2,520	0	2,520
	Vertical Force		Lb.	4,020	3,440	7,460	7,100	14,560
	Torque (SEE NOTE)		In. Lb.	29,100	25,300	54,400	0	54,400

* Acting at Payload ℄ only. All other loads acting through the ℄ of the transducers.
℄ transducers 16 in. below ℄ Payload at Sta. 126.4

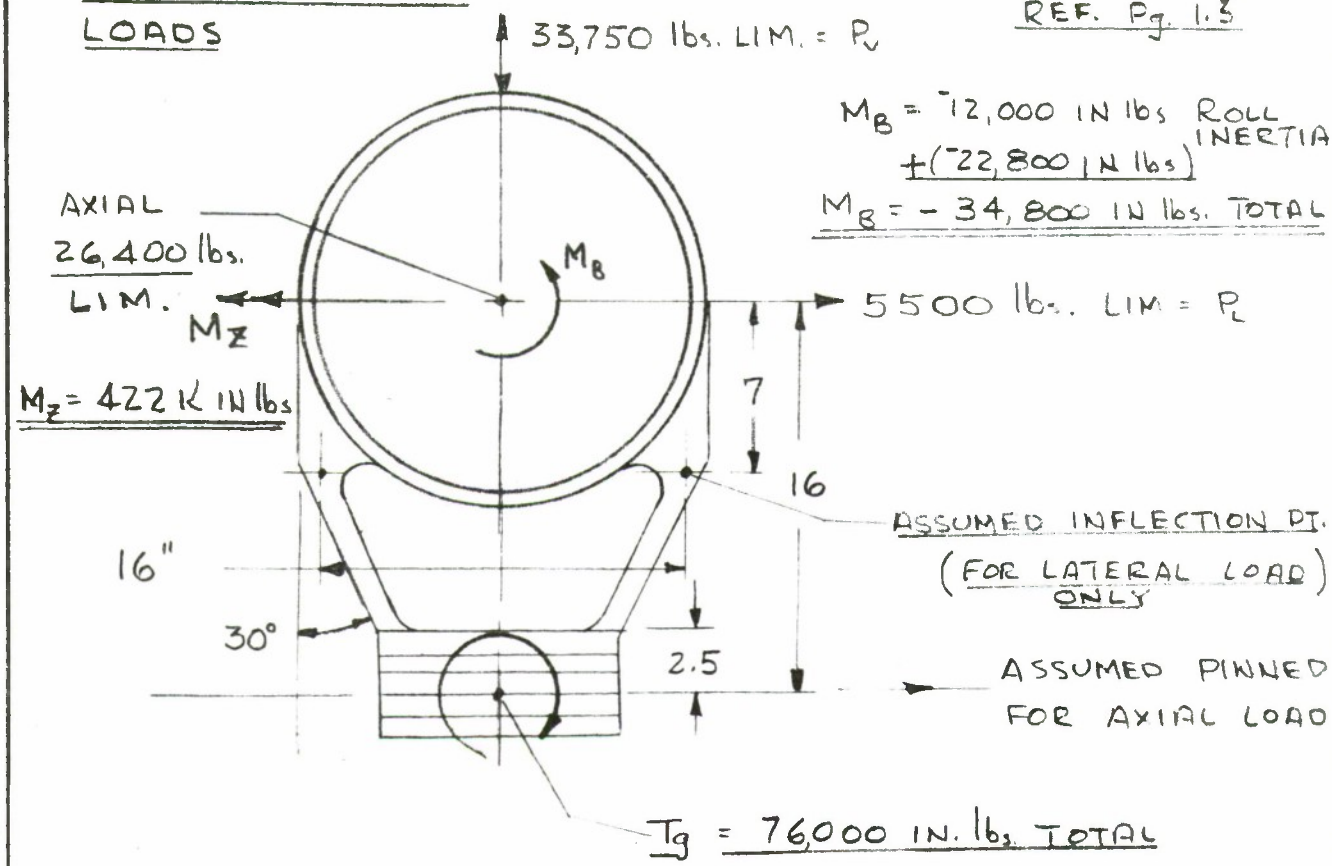
NOTE: Transducers assumed pinned in fore and aft direction.

Torque based on Shear transfer of 12 in. from ℄ Payload to ℄ transducer minus Roll Inertia. Torque will be increased for 16 in. Shear transfer.

SLED TEST ENGINE

STA. 124.4 JOINT LOADS

REF. Pg. 1.3



M_B = ⁻12,000 IN lbs ROLL INERTIA
+(⁻22,800 IN lbs)
M_B = −34,800 IN lbs. TOTAL

IF WE ASSUME THAT 70% OF BASE T_g GOES TO FORWARD LOAD CELL THEN 30% T_g MUST ADD TO M_B AT ℄ PAYLOAD.

$\Delta M_B = .30 \times 76000 = {}^-22800$ IN lbs.

TOTAL $M_B = -12000 - 22,800 = -34,800$ IN lbs

LOADS AT ASSUMED INFLECTION POINTS

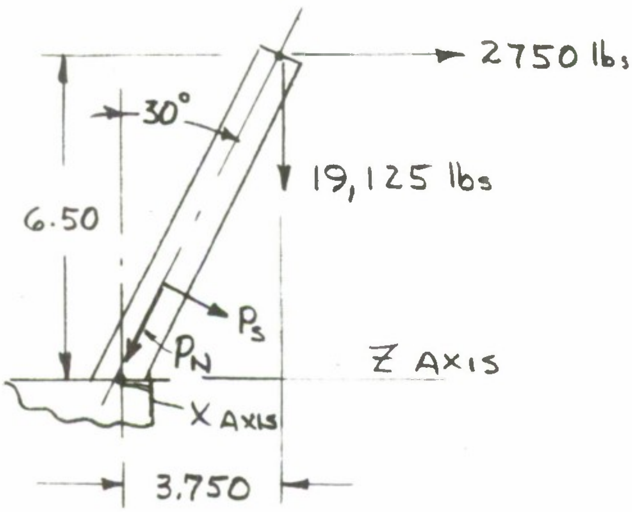
$$P_V = \frac{33,750}{2} \pm \frac{(5500 \times 7 - 34800)}{16} = 19,125 \text{ lbs. MAX / SIDE}$$

$P_L = 5500/2 = 2750$ lb./SIDE , $P_D = 26,400/2 = 13,200 \frac{\text{lbs}}{\text{SIDE}}$

$$M_Z = \frac{26,400(16-7)}{2} = 119,000 \text{ IN. lbs / SIDE}$$

SLED TEST ENGINE

STA 124.4 JOINT, MOUNT AT BASE



(CONSERVATIVELY NEGLECTING REDUNDANT FORCES DUE TO FRAME STIFFNESS)

$M_X = 2750 \times 6.50 + 19125 \times 3.75$

$= \underline{89,900 \text{ IN. lbs/SIDE}}$

$M_Z = \dfrac{26,400 \times 2.50}{2} = 33,000 \text{ IN. lbs}$

$M_Z' = 33000 \cos 30° = \underline{28,600 \text{ IN lbs}}$

$T_g = 33,000 \sin 30° = \underline{16,500 \text{ IN lbs}}$

$P_D = \dfrac{26,400}{2} = \underline{13,200} \text{ lbs}$

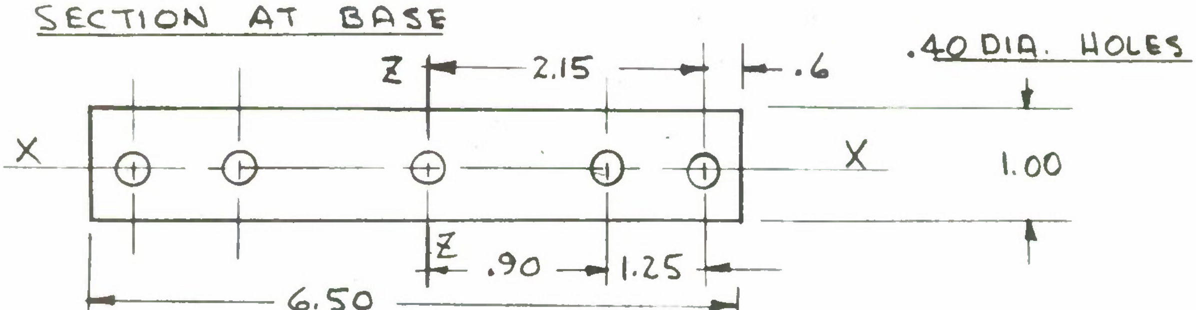
$P_S = 19,125 \sin 30° + 2750 \cos 30°$

$= \underline{11,940 \text{ lbs}}$

$P_N = 19125 \cos 30° - 2750 \sin 30°$

$= \underline{15,230 \text{ lbs}}$

SECTION AT BASE



$I_{X/Z} = \left[\dfrac{5.5}{12}(1) - 5(.0491)(.40)^4\right]/.50 = \underline{.9034 \text{ IN}^3}$

$I_{Z/X} = \left[\dfrac{1}{12}(5.5)^3 - 2(.126)\left[(.90)^2 + (2.15)^2\right]\right]/2.75 = \underline{4.53 \text{ IN}^3}$

$\text{AREA} = 1 \times 5.5 - 5 \times .126 = \underline{4.87 \text{ in}^3}$

SLED TEST ENGINE

STA 124.4 JOINT, MOUNT

SECTION AT BASE

$$f_{b\,MAX} = \frac{M_x}{I_x/z} + \frac{M_z}{I_z/x} = \frac{89.9K}{.9034} + \frac{33.0K}{4.53} = \underline{107.0\ KSI}$$

$$f_N = P_N/A = 15.230K/4.87 = \underline{3120\ psi}$$

COMBINED SHEAR, BENDING & COMP. AT MID-LONG SIDE

$$f_b = 99.6\ Ksi$$
$$f_n = \underline{3.12\ Ksi} \longrightarrow \underline{102.7\ KSi}$$
$$\tau = \frac{T_g}{Kbt^2} = \frac{16.5K}{.295(5.5)1} = 10.2\ Ksi$$
$$f_s = (B/A)1.5 = \frac{13200 \times 1.5}{4.87} = \underline{4.06\ Ksi} \longrightarrow 14.26\ Ksi$$

MAX. EQUIVALENT STRESS $= \left[(\sigma_N)^2 + 3(\sigma_{S+R})^2\right]^{\frac{1}{2}}$

$$= \left[(102.7)^2 + 3(14.26)^2\right]^{\frac{1}{2}} K$$
$$= \underline{105.5\ Ksi}$$

SECTION AT CORNER MORE CRITICAL

$f_b + f_N = (107.0 + 3.12)Ksi = \underline{1100\ Ksi\ \text{LIMIT}}$ (MOSTLY BEND.)

FOR 150 Ksi ULT, $F_{TY} = 132{,}000$ psi AT 70°F

AT 300°F, $F_{TY} = .94 \times 132{,}000 = 125{,}000$ psi

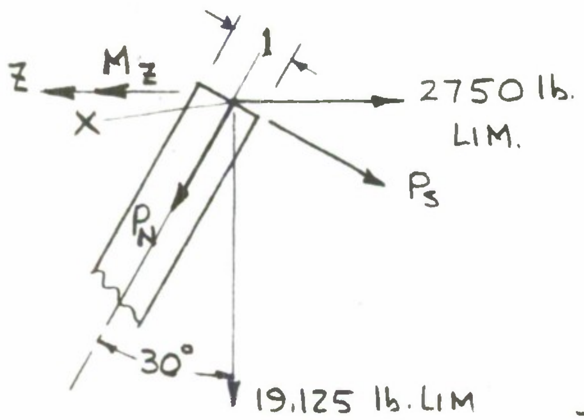
$F_{bY} \cong 1.1 \times 125{,}000 = 137$ Ksi PLASTIC BEND

$$\underline{M.S.} = \frac{137}{110.0} - 1 = \underline{.24}$$

SLED TEST ENGINE

STA 124.4 JOINT, MOUNT

SECTION AT INFLECTION POINTS



P_D = 13,200 lb. LIMIT
P_S = 11,940 lb. LIMIT
P_N = 15,230 lb. LIMIT

M_Z = 119,000 IN. lb. LIMIT

$M_Z{}'$ = 119,000 COS 30° = 103,000 IN. lb LIMIT

$T_{\mathcal{L}}$ = 119000 SIN 30° = 59500 IN. lb. LIMIT

SECTION IS 1 X 4

$$I_Z/x = \frac{1}{6}(4)^2 = 2.67 \text{ IN}^3$$

$$f_b = \frac{M_Z{}'}{I_Z/x} = \frac{103{,}000}{2.67} = 38{,}700 \text{ psi}$$

$$f_n = 15{,}230/4 = \underline{3{,}800 \text{ psi}}$$

$$f_b + f_n = \underline{42{,}500 \text{ psi}}$$

$$f_{s_1} = \frac{13{,}200 \times 1.5}{4} = 4{,}980 \text{ psi}$$

$$f_{s_2} = \frac{11940 \times 1.5}{4} = 4{,}480 \text{ psi}$$

$$\tau = \frac{T_{\mathcal{L}}}{Kbt^2} = \frac{59{,}500}{.282(4)1} = 52{,}600 \text{ psi}$$

AT MID POINT LONG SIDE $\tau + f_s = 52{,}600 + 4980 = \underline{57{,}580 \text{ psi}}$

EQUIVALENT STRESS $= \left[(42.5)^2 + 3(57.6)^2\right]^{1/2} \times K = \underline{\underline{109.0 \text{ K}}}$ YIELD

$F_{TY} = 132{,}000 \times .94 = 125{,}000$ psi @ 300°F

$$\underline{\underline{M.S.}} = \frac{125 \text{ K}}{109 \text{ K}} - 1 = \underline{\underline{.15}}$$

SLED TEST ENGINE

STA. 124.4 JOINT, MOUNT

AT ℄ PAYLOAD

$M_Z = 26{,}400 \times \frac{16}{2} = 211{,}000$ IN lb. /SIDE

ASSUME ½ MOMENT/SIDE REACTED BY TOP HALF OF MOUNT, ONE HALF BY BOTTOM

THEN M_Z /SIDE $= 211{,}000/2 =$ 105,500 IN lb /SIDE LIMIT

$P_T = 33{,}750/2 \times 2 =$ 8420 lb/SIDE LIMIT

$P_S = 5{,}506/2 \times 2 =$ 1370 lb/SIDE LIMIT

LET SECTION = .3125 x 4 PLUS BOLT WEB

$I_Z/x = \frac{.3125}{6}(4)^2 = .834 \text{ in}^3$

$A = 1.25 \text{ in}^2$

$f_b = 105500/.834 = 127{,}000$ psi

$f_t = 8420/1.25 = 7000$ psi

$F_{b_y} = 1.2 \times 125000 = 150{,}000$ psi @ 300°F PLASTIC BENDING

$F_{TY} = 125{,}000$ psi @ 300°F

$R_b = \frac{127}{150} = .847$

$R_t = \frac{7000}{125K} = .0056$

$R_b + R_t = .853$

$M.S. = \frac{1}{.853} - 1 = \underline{\underline{.17}}$

SLED TEST ENGINE

STA 124.4 JOINT MOUNT

BENDING ON MOUNT ℄ PAYLOAD

ELASTIC STABILITY OF SECTION

USE ROARK, pg. 344, CASE 15b

FOR NARROW REST SECTION UNDER PURE BENDING
ENDS HELD FIXED

$$M' = \frac{2\pi b^3 d \sqrt{EG\left(1 - .63\frac{b}{d}\right)}}{6L}$$

WHERE: $b = .3125$
$d = 4.00$
$E = 30 \times 10^6$
$G = 11.5 \times 10^6$
$L \cong R \cong 8''$
M' = ALLOWABLE MOMENT

$$M' = \frac{6.28(1)\,4\sqrt{30 \times 11.5\left(1 - .63\left(\frac{1}{4}\right)\right)10^{12}}}{6 \times 8}$$

$= .524 \times 10^6 (17.07)$
$= \underline{8.93 \times 10^6 \text{ IN lbs}}$

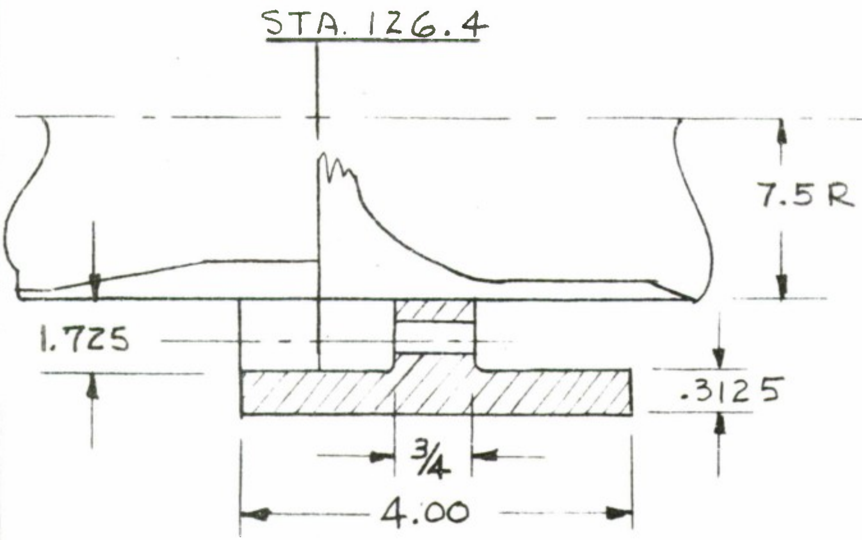
SINCE M APPLIED IS ONLY 105,500 in lbs

ELASTIC M.S. = LARGE

SLED TEST ENGINE

STA 124.4

TORSION ON SUPPORT FLANGE - 4130 STL. H.T. TO 150 KSI



FROM pg. (2.20) MAX. SHEAR LOAD ON .75 FLANGE = 3330 lbs/in.

ASSUME TORSION $= P_s \frac{L}{2}\frac{R}{2}$ * WHERE $P_s = 3330$ lb/in.

$L/2 = 1.125/2$

$= 3330(.5625)(3.75)$ $R/2 = 7.5/2$

$= 7030$ in. lbs

$$\tau = \frac{3T_{¢}}{\Sigma l t^2} = \frac{3 \times 7030}{\left(1.125(.75)^2 + 4(.3125)^2\right)} = 20600 \text{ psi AT CENTER}$$

FOR 4130 H.T. TO 150 KSI $F_{SY} = 135000 \times .6 = 81000$ psi AT 70°F

F_{SY} @ 300°F = .94 × 81,000 = 76,000 psi

$$M.S. = \frac{76{,}000}{20{,}600} - 1 = \text{LARGE}$$

* MAX. RUNNING SHEAR IS MOSTLY DUE TO BODY BENDING MOMENT AND IS A FUNCTION OF R SIN Θ AROUND PERIPHERY.

SLED TEST ENGINE

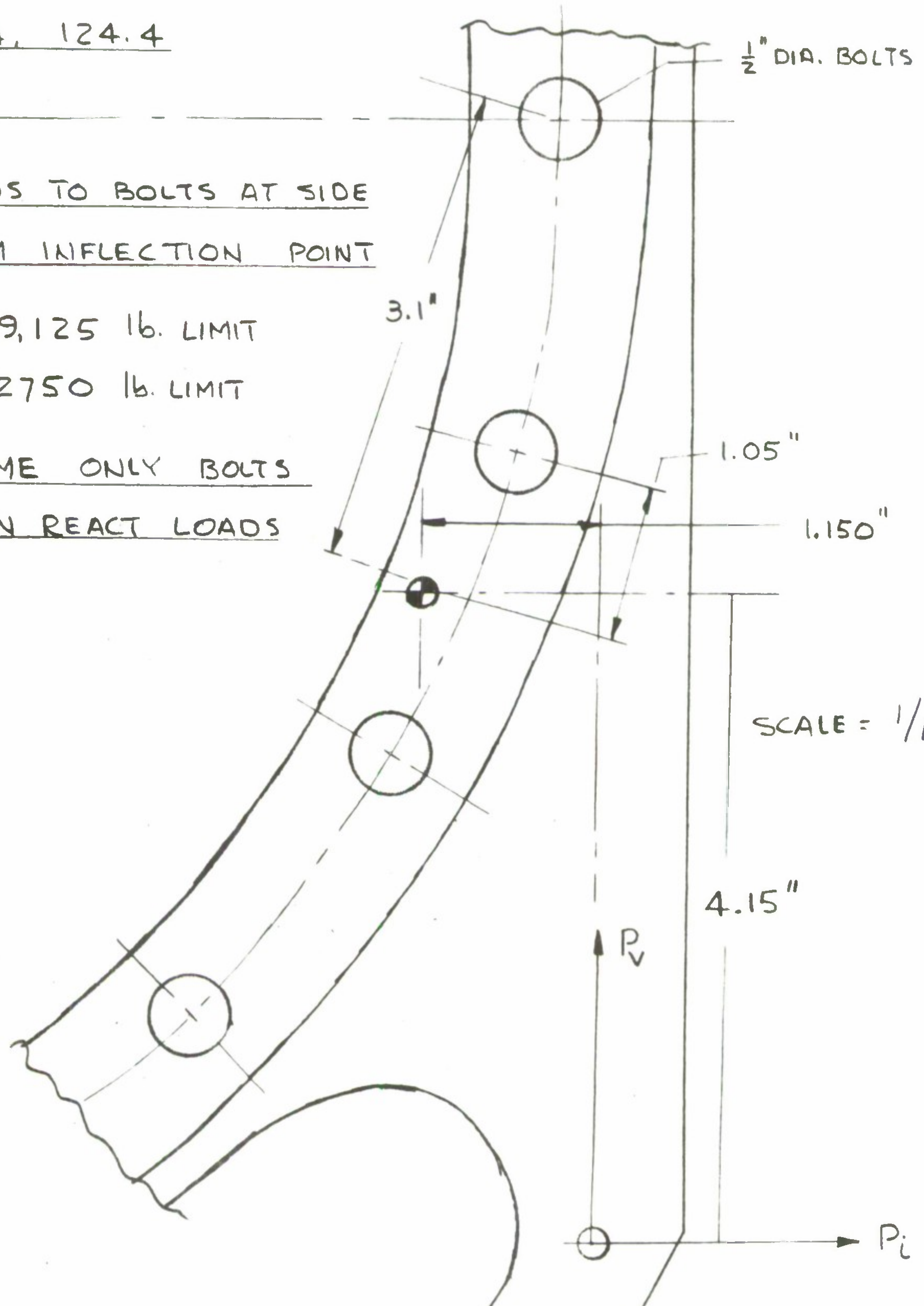
STA. 124.4

LOADS TO BOLTS AT SIDE FROM INFLECTION POINT

P_V = 19,125 lb. LIMIT

P_L = 2750 lb. LIMIT

ASSUME ONLY BOLTS SHOWN REACT LOADS



SLED TEST ENGINE

LOADS TO FRAME ATTACH BOLTS - STA. 124.4

FROM LOADS AT INFLECTION POINT

$\Sigma M_{cg} = 19{,}100 \times 1.15 + 2750 \times 4.15 = 33{,}400$ in lbs.*

$I_{BOLTS} = 2\left[(3.1)^2 + (1.05)^2\right] = 21.4$ in^4

$$P_{S\,MAX} = \frac{33{,}400 \times 3.1}{21.4} + \frac{19{,}100}{4} \rightarrow \frac{2750}{4}$$

$= 4850 + 4770 \rightarrow 688$

$=$ 9600 lb. LIMIT SHEAR CONSERVATIVE

$f_s = \dfrac{9600}{.197} = 48{,}700$ psi ON SHANK

$f_t =$ TENSION LOAD/BOLT/AREA $= \dfrac{5130}{.197} = 26{,}000$ psi (pg. 2.19) ON SHANK

COMBINED STRESS EFFECTIVE σ_e $= \left[\sigma_t^2 + 3\sigma_s^2\right]^{1/2}$

$= \left[(26.0)^2 + 3(48.7)^2\right]^{\frac{1}{2}} \times 1000 =$ 88,000 psi YIELD

BUT ABOVE IS CONSERVATIVE (MORE BOLTS WILL TAKE SHEAR)

LET $F_{TY} = 103{,}000$ psi YIELD FOR AN BOLT AT 70°F

$= .94 \times 103{,}000$ psi $= 97{,}000$ psi YIELD AT 300°F

$$\text{M.S.} = \frac{97{,}000}{88{,}000} - 1 = .10$$

* CONSERVATIVE SINCE A PART OF MOMENT WILL REMAIN IN MOUNT FRAME PROPORTIONAL TO RELATIVE STIFFNESS.

SLED TEST ENGINE

STA. 124.4

ATTACH BOLTS TO SUPPORT FRAME

M_Y = 53,400 in. lb. ABOUT VERTICAL AXIS

M_Z = 490,000 in. lb. ABOUT HORIZONTAL AXIS

M_X = 34,800 in. lb. ABOUT LONGITUDINAL AXIS (pg. 2.1)

AXIAL = 26,400 lb.
LAT. = 5550 lb.
VERT. = 33,750 lb

RESULTANT SHEAR LOAD = $\left[(5.53)^2 + (33.75)^2\right]^{1/2} \times 1000$ = 38,100 lb.

SHEAR DUE TO TORQUE = $\frac{M_x}{R}$ = 34,800/8 = 4350 lb.

ASSUME TOTAL SHEAR TAKEN BY 8-½" DIA. BOLTS (CONSERVATIVE)

$f_s = \frac{(38,100+4350}{8 \times .197} = 26.900$ psi SHEAR STRESS

MAX. RESULTANT MOMENT = $\left[(53.4)^2 + (490)^2\right]^{1/2} \times 1000 = 493,000$ in. lb.

MAX. TENSION LOAD / BOLT = $\frac{2M}{RN}$ R = 8"
N = 24

$$P_T = \frac{2 \times 493,000}{8 \times 24} = 5130 \text{ lb.}$$

f_t = 5130/.1965 = 26,200 psi

$\sigma_c = \left[(26.2)^2 + 3(26.9)^2\right]^{1/2} \times 1000$ = 53500 psi ON SHANK

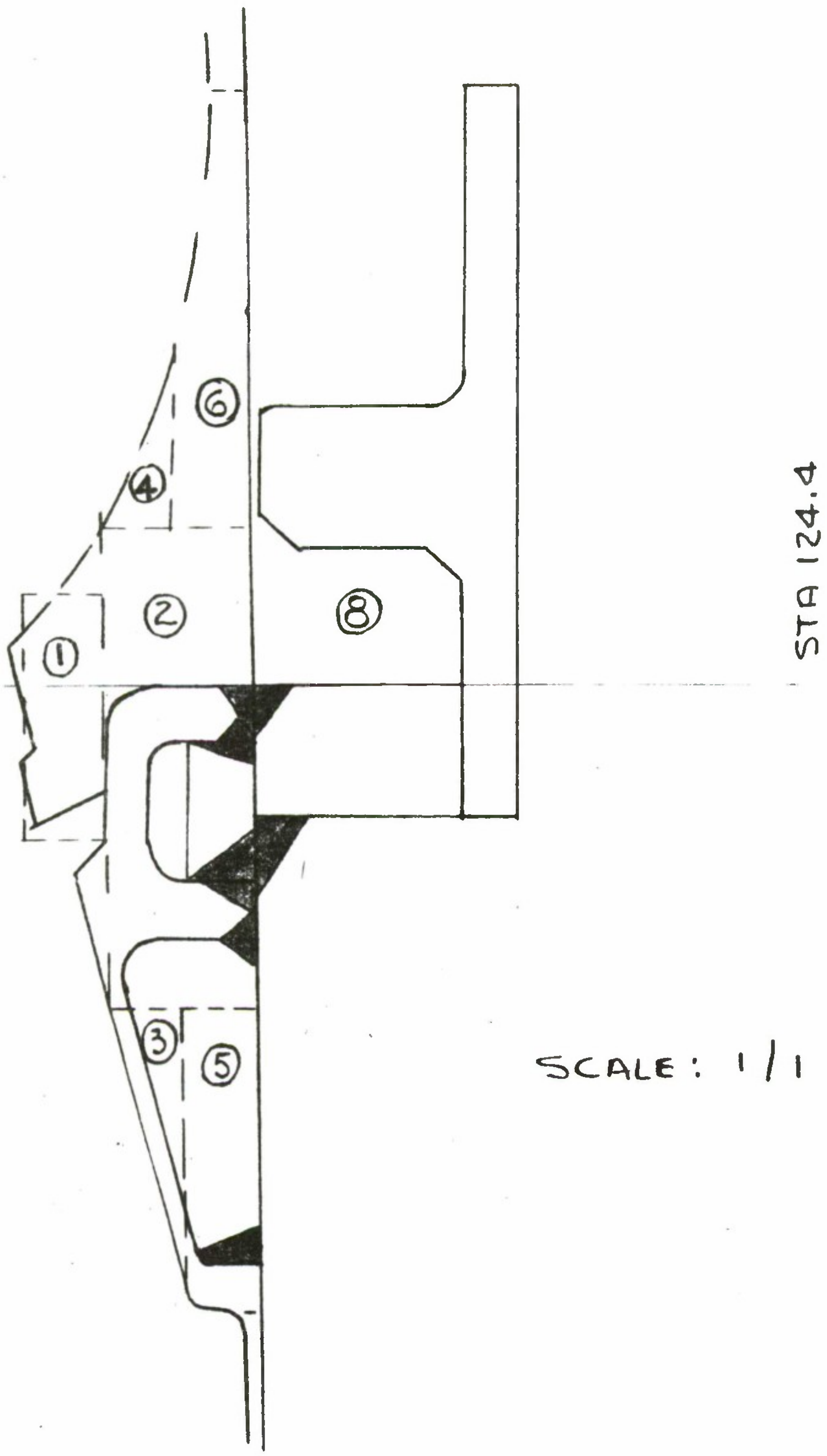
FOR AN BOLT, F_{TY} = 103.000 psi MIN (F_{TU} = 125 KSi)

$$M.S. = \frac{103}{53.5} - 1 = .92$$

P_{TU} = 18900 lb. ULT. ON THREAD

TENSION M.S. = $\frac{18,900}{1.5 \times 5180} - 1$ = LARGE

STA 124.4 FRAME SECTIONS

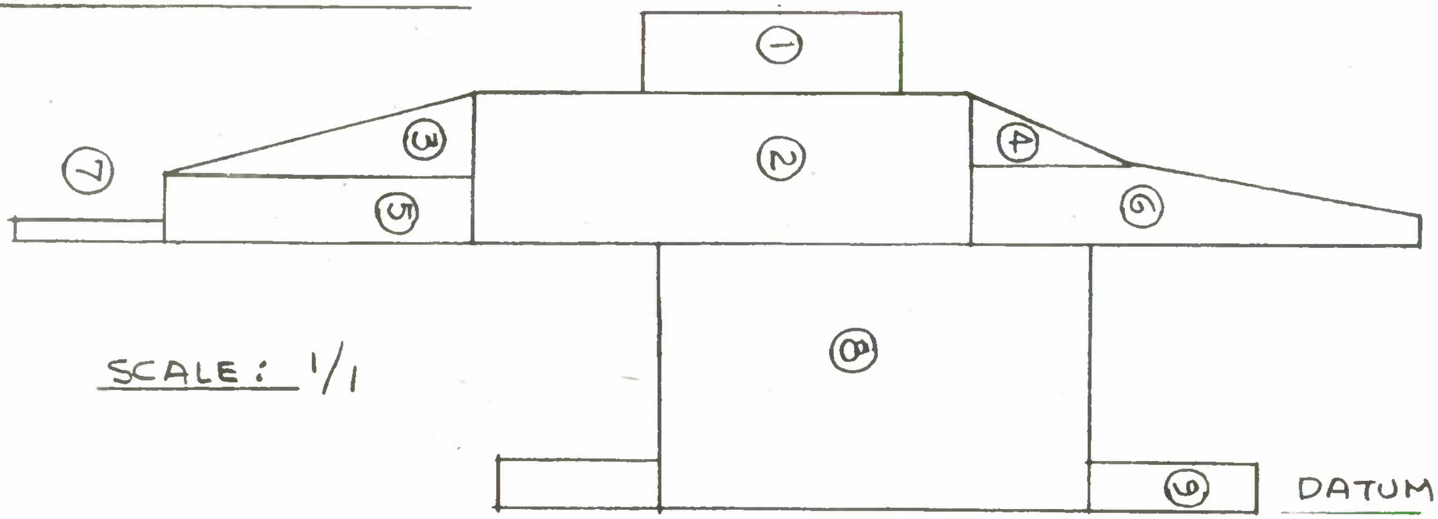


SCALE: 1/1

SLED TEST ENGINE

STA 124.4 FRAME SECTIONS

EQUIVALENT SECTIONS



SCALE: 1/1

PART	AREA	Y	AY	AY²	I_o
1	.54	2.4	1.30	3.12	–
2	2.08	1.8	3.75	6.75	.111
3	.32	1.87	.60	1.12	–
4	.14	1.95	.273	.532	–
5	.606	1.90	1.152	2.190	–
6	.762	1.60	1.220	1.950	–
7	.06	1.42	.085	.120	
8	3.10	.688	2.13	1.465	.512
9	.547	.156	.0855	.013	–
	8.155	$\bar{Y} = 1.30$	10.5955	17.260	.623

$$\underline{\underline{I}} = .623 + 17.260 - 1.30\,(10.60) = \underline{\underline{4.083\ in^4}}$$

SLED TEST ENGINE

RELATIVE FRAME STIFFNESS - STA 124.4

$$L = L_o\left(1 + \frac{G}{R}\,\frac{L'}{t}\,\frac{L_o^2}{R^2}\right)$$

$$= 32\left(1 + .38 \times \frac{(32)^2}{64}\right)$$

WHERE:

$L_o = 156 - 124 = 32$ in.

$t' = t = .070$

$R = 8, \quad R^2 = 64$

$\frac{G}{E} = .38$

$L = 226$ in.

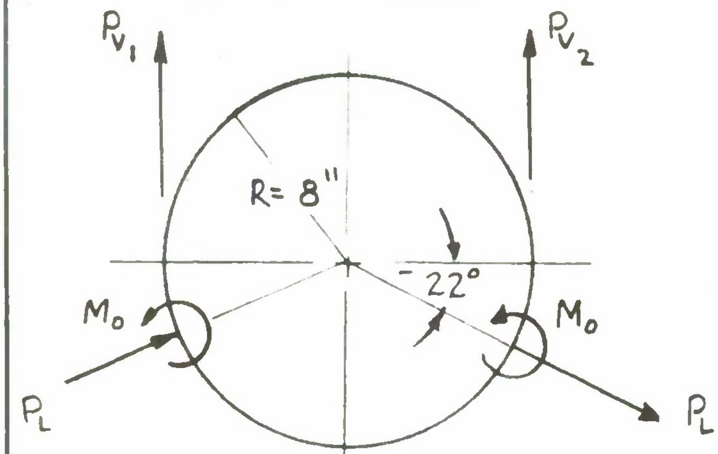
$$d = \frac{G t R^4}{E I L} = \frac{.38(.070)(8)^4}{4.08 \times 226} = .118 \longrightarrow 0.0$$

$$K = \frac{R t G}{L} = \frac{8(.070)\,11.5 \times 10^6}{226} = 28{,}500$$

FROM ABOVE, SINCE $d \approx 0$, FREE RING FORMULAS WILL BE USED

SLED TEST ENGINE

STA 124.4 RINGS



$P_V = 16875 \pm 2250$ lb.

$P_L = 2750$ lb.

$M_o = 11,400$ in. lb.

$P_{V_1} = 19,125$ lb (REF. pg. 2.9)

$P_{V_2} = 14,625$ lb.

$\theta°$	C_{HP_V}	M_{P_V}	C_{MP_L}	M_{P_L}	$C_{M M_o}$	M_{M_o}	ΣM
-22°	0	0	(.07 - .063)	+ 154	(+.32 - .06)	2960	3114 in. lb.
+22°	(.061 + .044)	- 14500	(.07 - .018)	- 1140	(-.32 - .10)	-4800	-20440 in. lb.

$M_{PV} = C_M P_V R$

$M_{PL} = C_M P_L R$

$M_{MS} = C_M M_o$

M_{MAX} AT +22° = - 20440 in. lb.

$$f_{b\,MAX} = \frac{-20440 \times 1.300}{4.083} = 6500 \text{ psi} \; *$$

FOR 4340 STL. H.T. TO 150,000 psi UTS @ 70°F

F_{TY} @ 300°F = 125,000 psi

M.S. = LARGE

*REDUCTION OF MODULUS DUE TO BOLT HOLES IS SMALL ≅ 20%

SLED TEST ENGINE

STA 124.4

BENDING ON 4130 STL., 321 CRES FLANGES

LET ARM = .625/2 = .3125 in. FOR CLAMPED BOLT

$M = 3330 \times .3125 = 1040$ in. lb.

$$f_b = \frac{1040 \times 6}{1 \times (.75)^2} = 11{,}100 \text{ psi}$$

IF WE USE 1.5 STRESS CONCENTRATION FACTOR

$F_{TY} = 25000$ psi @ 300°F (321 CRES)

$F_{bY} = 1.22 \times 25{,}000 \times .90$ WELD EFF. $= 27{,}000$ psi

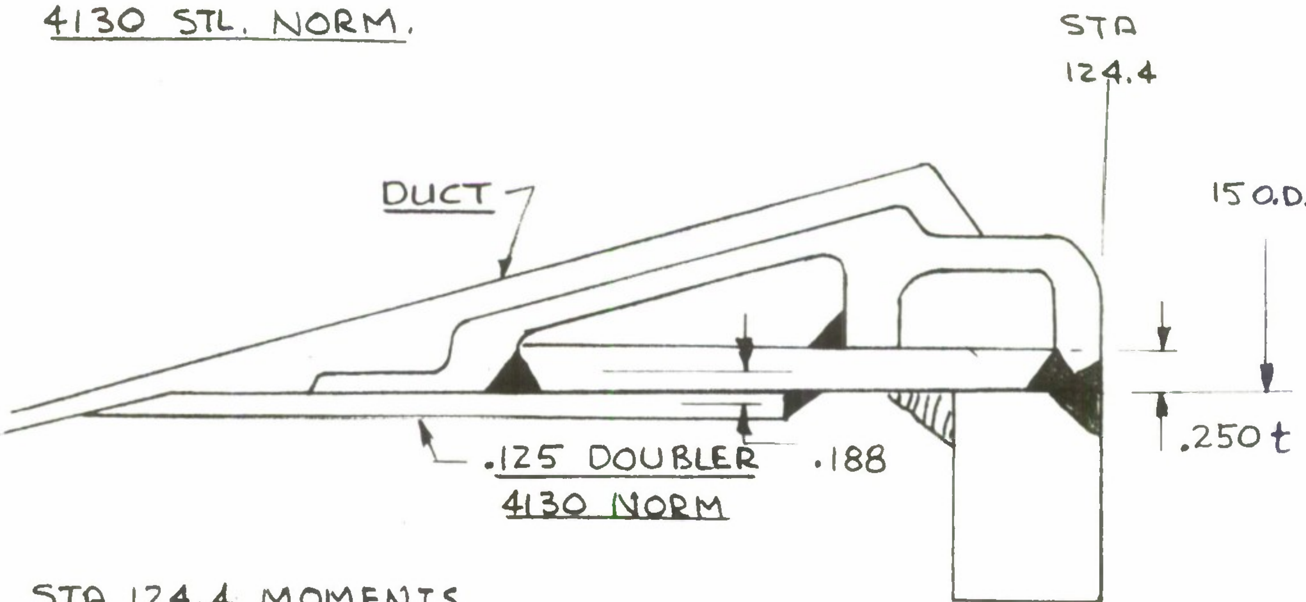
$$\text{M.S.} = \frac{27{,}000}{11{,}100 \times 1.5} - 1 = \underline{\underline{.62}}$$

SLED TEST ENGINE

STA 124.4 JOINT

LOADS TO DOUBLER PLATES

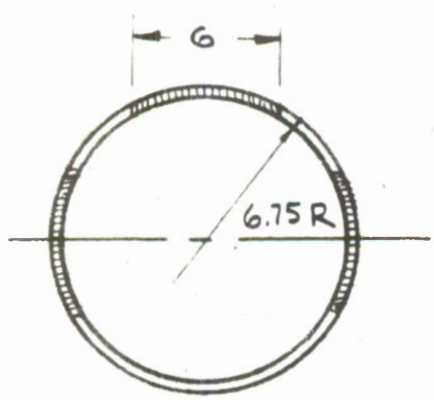
4130 STL. NORM.



STA 124.4 MOMENTS

$M_z = 490{,}000$ in. lb.

$M_y = 53{,}400$ in. lb. RESULTANT M = 493,000 in. lb.



NET I OF SECTION

$$I = \pi (6.75)^3 t - 2\left[(6)t(L)^2\right] - 2t\frac{(L)^3}{12}$$

$$I = (967 - 431 - 36)\,t$$

$$I = 500\,t$$

$$I/y = \frac{500\,t}{6} = \underline{83.3\,t}$$

LOAD/in. = 493,000/83.3 = 5920 lb/in. MAX

SLED TEST ENGINE

STA. 124.4 JOINT

LOAD & STRESS ON DOUBLER 4130 STL. NORM

$P = 5920$ lb/in. MAX. (pg. 2.17)

$f_t = 5970/.125 = 47400$ psi

FOR .90 WELD EFFICIENCY & .94 TEMP. REDUCTION

F_{TY} @ 300°F = .9 x .94 x 75,000 = 63,500 psi

AT WELD $\quad M.S. = \dfrac{63,500}{47,400} - 1 = \underline{\underline{.34}}$

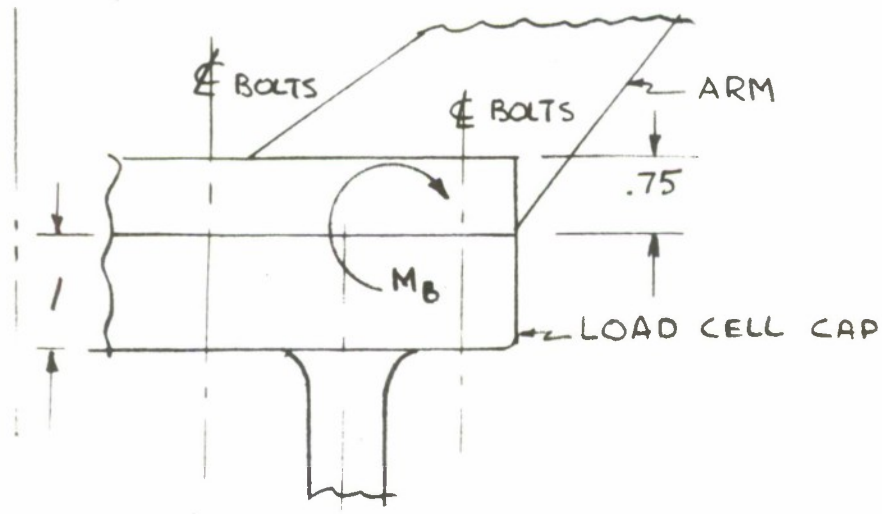
VERY LITTLE MOMENT FROM OFFSET OF .188 in.
GOES INTO DOUBLER AT THIS END DUE TO
VERY LARGE STIFFNESS OF RING AT STA. 124.0

SLED TEST ENGINE

STA. 124.4

LOADS & MOMENTS TO BASE

(1) MOMENT DISTRIBUTION TO BASE



FROM pg 2.2, $M_B = M_x = 89{,}900$ in lb.

$I_{BASE} = K(.75)^3 = .42\,K$

$I_{LOAD\ CELL} = K(1.0)^3 = 1.0\,K$

MOMENT TO BASE $= \dfrac{M_x(.42)K}{(1.0+.42)K} = \underline{89{,}900 \times .296}$

$= \underline{26{,}300 \text{ in lb.}}$

SECTION IS .75 t, x 5.56 WIDE WITH 4-.400 HOLES + 1-.500 HOLE

$I/y = \dfrac{(5.50-2.10)}{6}(.75)^2 = .319$

FOR .50 DIA., 1 in. SPACE ($K_t \cong \underline{1.7-1.8}$ PETERSEN FIG. 36)

$f_{b_1} = 26{,}300\ K_t/.319 = \underline{82{,}500 \text{ psi } K_t}$

$F_{TY} = 125{,}000$ psi @ 300°F FOR H.T. TO 150 Ksi ULT. @ 700°F

$F_{bY} = 1.22 \times 125{,}000 = 152{,}000$ psi

$\underline{M.S.} = \dfrac{152}{1.75 \times 82.5} - 1 = \underline{.05}$

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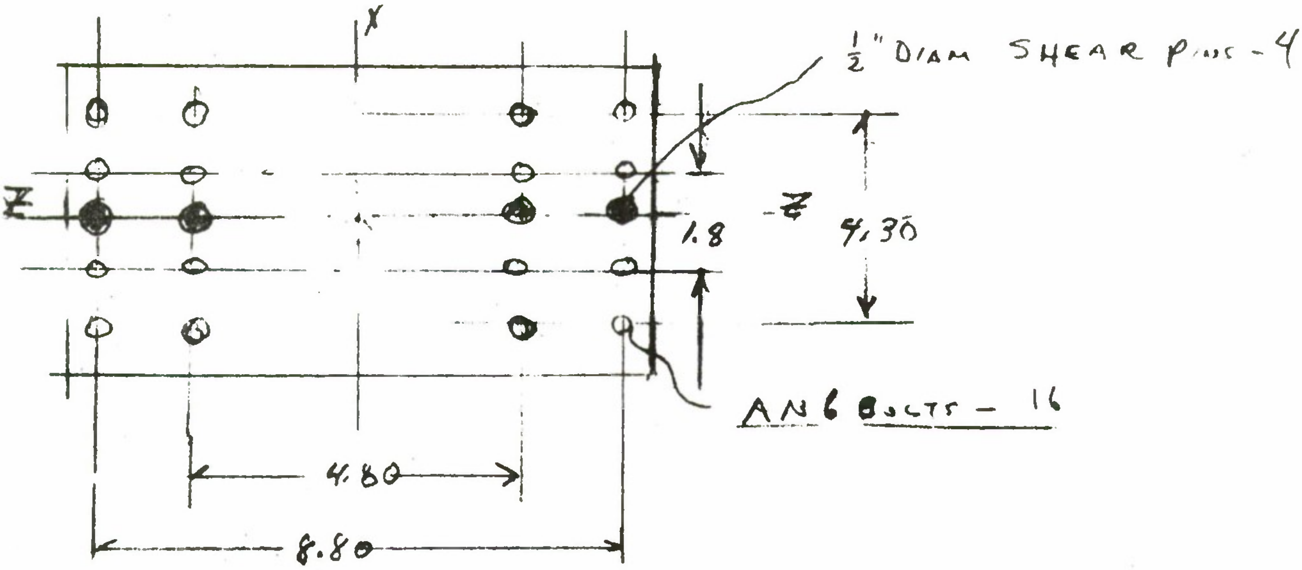
STA 124.4

LOADS AND MOMENTS TO BASE



$I_{XX} = 4 \times 2\left[(4.4)^2 + (2.4)^2\right] = 202.0$ TENSION BOLTS ONLY

$P_V = 33750\#$ LIMIT TOTAL, $P_L = 5500\#$, $P_{DRAG} = 26400\#$ LIM

$M_X = 76000 \times .70 = 53000$ IN# LIMIT (Ref pg 1

RESULTANT SHEAR $= \left[(5.5)^2 + (26.4)^2\right]^{\frac{1}{2}} \times 1000 = 27000\#$ LIM

MAX TENSION LOAD TO BOLT

$$P_T = \frac{53000 \times 4.4}{202} + \frac{33750}{16} = 3270\# \text{ LIMIT}$$

$P_{ALLOWABLE} = 10300\#$ FOR 125 KSI, (ULT. LOAD @ 70°F)

SHOULD USE 125 KSI UTS BOLTS — M.S. = LARGE (WITH 1.5 FACTOR)

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STA 124.4

LOADS AND MOMENTS TO BASE

SHEAR ON ATTACH PINS

RESULTANT $P_L + P_{DRAG}$ = 27000 # LIMIT (pg 2.17)

ASSUME TAKEN BY 3 ½" DIAM SHEAR PINS

$P_S = 27000/3 = 9000$ # LIM

SHEAR AREA: $\frac{\pi}{4}(.50)^2 = .197$

$f_s = 9000/.197 = 45600$ psi LIMIT

FOR 160 KSI SHEAR PINS

F_{SU} = 100,000 psi @ 70°F
= 94,000 psi @ 300°F

FOR FTU = 160,000 psi PIN.

SHEAR M.S. = $\frac{94}{45.6 \times 1.5} - 1 = .37$
(WITH 1.5 ULT. FACTOR)

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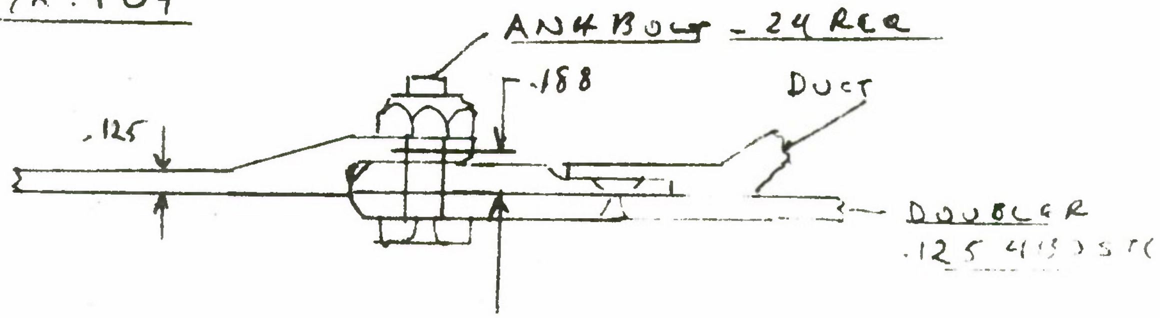
STA. 109



MOMENT AT STA 109 = 139000 in# LIMIT RESULTANT

LOAD/INCH $= \frac{M}{\pi R^2} = \frac{139000}{\pi(7.5)^2} = 786\ \#/in = P$

FOR BENDING ON FWD SKIN

ASSUME DOUBLER + FWD SKIN HAVE EQUAL STIFFNESS

$M = Pe/2 = 786 \times .188/2 = 74$ in#/in

$f_b = \frac{6M}{t^2} = \frac{6 \times 74}{(.125)^2} = 28400$ psi

$f_t = \frac{786}{.125} = 6300$ psi

Correcting for Bolt Spacing Increase of Stress

$S = \pi D/N = \pi(15)/24 = 1.965$ in/bolt

$K = \frac{1.965}{(1.965 - .25)} = 1.14$

Total $f_b + f_t = (28400 + 6300)(1.14) = 39700$ psi

$F_{ty} = .94 \times 75000$ psi for NORM 4130 AT 300°F
$= 70500$ psi.

$M.S. = \frac{70500}{39700} - 1 = .77$

SLED TEST ENG

STA 109

$M_Z = 123{,}000$ IN # LIMIT

$M_Y = 65{,}000$ IN # LIMIT

RESULTANT $M = \left[(123)^2 + (65)^2\right]^{\frac{1}{2}} \times 1000 = 139000$ IN # LIMIT

MOMENT TRANFERED BY 24 AN 4 BOLTS

$P_s = \dfrac{2M}{RN}$ $R = 7.5$ IN, $N = 24$

$P_s = \dfrac{2 \times 139000}{7.5 \cdot 24} = 1540$ # SHEAR/BOLT MAX

BEARING IN .125 4130 STL NORM

$F_{br_y} = .97 \times 129000 = 125{,}000$ PSI FOR NORM 4130, 300°F (MIL-HANDBK 5)

$P_{br_y} = .125 \times .25 \times 125000 = 3910$ #

$P_{s_y} = 3680/1.25 = 2950$ # SHEAR YIELD

BOLT M.S. $= \dfrac{2950}{1540} - 1 = .92$

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TAIL PIPE ANALYSIS - STA 130 - L-605 MATL

FOR AFT REACTION AT STA 160.3 (Ref pg 3.1)

RESULTANT SHEAR ON PIPE $= \left[(14560)^2 + (2520)^2\right]^{\frac{1}{2}} = 14800^{\#}$

AT STA. 130 (15.0 OD x .070 WALL AT 300°F)

$F_{tu} = 170K$
$F_{ty} = 130K$
20% C.W.
(AeroSpace Metals HandBk)

$$f_s = \frac{V}{\pi R t} = \frac{14800}{\pi(7.5)(.070)} = 9000 \text{ psi}$$

$F_s = .6 \times 130{,}000 = 78000$ psi YIELD @ 300°F

FOR RAMJET MODE ($P_1 = 135$ psi)

$$f_{Hoop} = \frac{135}{1400} \times 170{,}000 = 16{,}400 \text{ psi}$$

$$f_{axial} = \frac{135}{1400} \times 86700 = 8{,}370 \text{ psi}$$

$$\sigma_e = (\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau^2)^{\frac{1}{2}}$$

$$\sigma_e = \left[(16.4)^2 + (8.37)^2 - (16.4 \times 8.37) + 3(9.0)^2\right]^{\frac{1}{2}} \times 1000 = 21100 \text{ psi}$$

$F_{TY} = 130{,}000$ psi

$$M.S. = \frac{130}{21.1} - 1 = \text{LARGE}$$

BENDING STRESS STA 130 (Ref pgs 3.1, 3.2)

$$M = 14800(160.4 - 130) + 965 \times (7.5 + \frac{4.5}{2}) = 453{,}400 \text{ in}^{\#}$$

$$f_b = \frac{M}{\pi R^2 t} = \frac{453{,}400}{\pi(7.5)^2(.070)} = 37400 \text{ psi LIMIT}$$

$f_{hoop} = 16{,}400$ psi FROM PRESSURE

$f_{axial} = 8370$ psi FROM PRESS

$f_b + f_{axial} = 8370 + 37400 = 45770$ psi

$$\sigma_e = \left[(16.4)^2 + (45.8)^2 - (16.4 \times 45.8)\right]^{\frac{1}{2}} \times 1000 = 40200 \text{ psi}$$

$F_{TY} = 130{,}000$ psi

$$M.S. = \frac{130}{45.8} - 1 = \text{LARGE}$$

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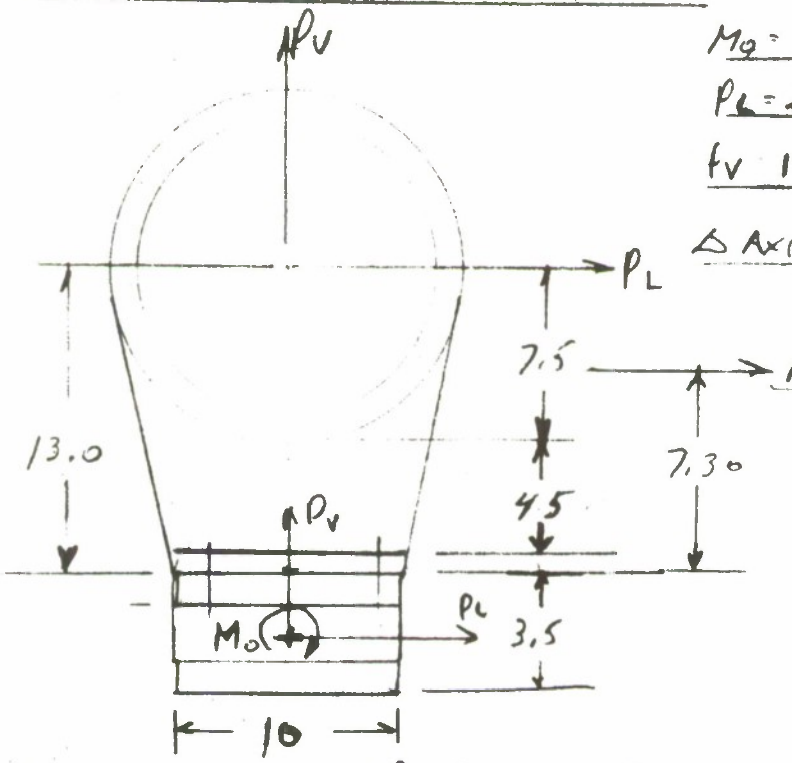
FLEXURES STA 16 & 34

$M_g = T_s = 22800$ IN# (A_j 2.1)

$P_L = 2520$# LIMIT

P_V 14560# " (P_L 1.3)

Δ AXIAL = $\pm .15$ IN FROM THERMAL EXPANSION



ASSUME ONE PLATE TO REACT LOADS.

ASSUME SIDE LOAD APPLIED $\frac{22800}{2520} = 9.05''$ FROM ℄ CELL

MOMENT FROM $\Delta = \pm .15$ IN

$$\delta_A = \frac{2P(L/2)^3}{3EI}, \quad P_A = \frac{3}{2}\frac{\delta EI}{(L/2)^3}, \quad M = \frac{L}{2} \times P_{AXIAL}$$

$L = 4.5''$

$$M = \frac{3}{2}\frac{\delta EI}{(L/2)^2} = \frac{1.5(.15)(30)10^6}{(2.25)^2}\,\frac{10(t)^3}{12}$$

$$M = 1.11 \times 10^{+6} t^3$$

$$f_b = \frac{1.11 \times 10^{+6} t^3 \times 6}{10 t^2} = .666 \times 10^6 t$$

$$P_x = 1.11 \times 10^6 t^3 / (L/2) = .495 \times 10^6 t^3$$

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FLEXURES - STA 160.34

SECTION AT BASE

$M_x = 2520 \times 7.3 = 18400$ in#

$M_{z_1} = 14560 \times .\frac{15}{2} = 1090$ in#

$$f_{b_{max}} = .666 \times t \times 10^6 + \frac{18400 \times 6}{(10)^2 t} + \frac{1090 \times 6}{10 t^2} + \frac{14560}{10t}$$

DIFFERENTIATE & SET TO ZERO

$$0 = .666 \times 10^6 - \frac{2560}{t^2} - 2 \times 654 / t^3 = 0$$

$$0 = .666 \times 10^6 t^3 - 2560t = 1308$$

$$t^3 - .003840t = .001960$$

$$t^3 = .00384t + .001960$$

LET: $p = \frac{.00384}{3}$, $q = .001960/2$

$p^3 = (.00128)^3$, $q^2 = (.00098)^2$

$p^3 = .0021 \times 10^{-6}$, $q^2 = .96 \times 10^{-6}$

$q^2 - p^3 = .959 \times 10^{-6}$ positive ∴ ONE REAL ROOT

$$t = X = \sqrt[3]{q + (q^2 - p^3)^{\frac{1}{2}}} + \sqrt[3]{q - (q^2 - p^3)^{\frac{1}{2}}}$$

0

$$= (.00098 + .000979)^{\frac{1}{3}} + (.000980 - .0009793)^{\frac{1}{3}}$$

0

$t = .125 + .009 = .134 \rightarrow .125$ IN.

$P_x = .495 \times 10^6 (.120)^3 = 965$# FROM AT

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FLEXURES - STA 160.34

SECTION AT BASE $t = .125$ 4130 ... 160 KSI

$$f_b + f_t = .666 \times .125 \times .06 + \frac{(184 \times 6 + 1456)}{.125} + \frac{109 \times 6}{(.125)^2}$$

$$= 83300 + 20500 + 41800$$

$$= 145600 \text{ psi}$$

$F_{ty} = 131000$ psi @ 300°F ; $F_{tu} = .96 \times 160$ KSI = 154000 psi @ 300°F

$F_{bu} = 154000 \times 1.45 = 223{,}000$ psi PLASTIC BENDING

$f_{b\,alone} = 145600 - 14560/1.25 = 134000$ psi

$f_c = 11600$ psi

$\frac{L}{r} = \frac{4.5/2}{.289 \times .125} = 62.5$ FOR FIXED ENDED COLUMN. INFLECTION POINT CANNOT DISPLACE AXIALLY.

$F_c = \frac{28}{30} \times 70000$ psi ULT = 65300 psi ULT AT 300°F COLUMN ALLOWABLE

$$R_c = \frac{11600 \times 1.25}{65300} = .222$$

$$R_b = \frac{134000 \times 1.25}{223000} = .750$$

$$M.S. = \frac{1}{.222 + .75} - 1 = .03 \text{ ULT}$$

(FOR 1.25 ULT FACTOR)

$$R_{by} = \frac{134000}{1.22 \times 131000} = .84$$

$$R_{cy} = \frac{11600}{131000} = .0885$$

$R_b + R_c$ .929

$$M.S. = \frac{1}{.929} - 1 = .08 \text{ YIELD}$$

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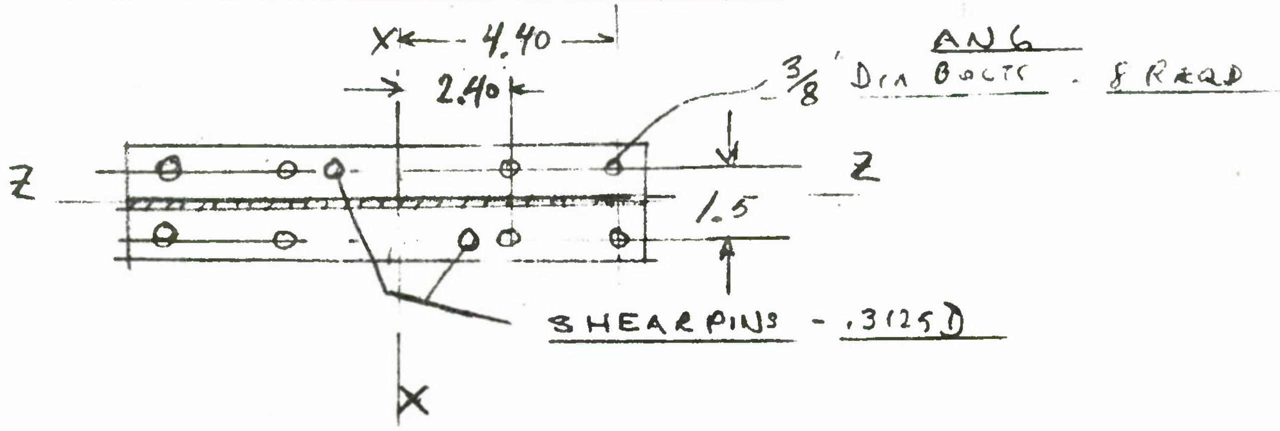
LOADS TO BASE BOLTS STA 160.34



$P_V = 14560^{\#}$ TOTAL LIMIT

$P_L = 2520^{\#}$ TOTAL LIM

$P_X = 965^{\#}$ (pg 3.2)

$M_X = 18400$ in# (pg 3.2)

$M_Z = 14560 \times .15/2 + 965 \;\frac{4.5}{2} = 3260$ in#

$I_{xx} = 2 \times 2\left[(4.40)^2 + (2.4)^2\right] = 100.64 \text{ in}^2$

TENSION TO MOST LOADED BOLT - AN6

$P_T = \frac{18400 \times 4.4}{100.6} + \frac{3260}{1.5 \times 4} + \frac{14560}{8} = 3170^{\#}$ LIMIT

$= 4750^{\#}$ ULT (1.5 FACT)

MAX SHEAR $= 2520 \oplus 965 = 2690^{\#}$ LIMIT RESULTANT

AN6 BOLTS. $P_{TU} = 10300^{\#}$ TENSION ULT/BOLT FOR 125 KSI ULT

.3125D. SHEAR PINS $P_{SU} = 7700^{\#}$ ULT/PIN FOR 160 KSI ULT

M.S = LARGE

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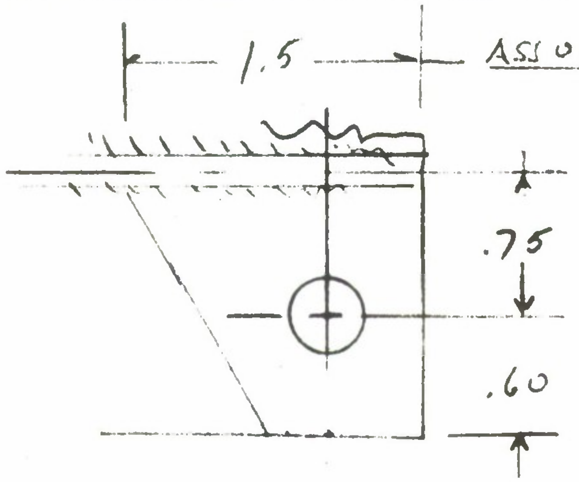
LOADS + STRESS ON BASE - STA 160.34

MAX LOAD / BOLT = 3170 # TENSION LIMIT

ASSUMED EFFECTIVE WIDTH



IF WE ASSUME ZERO BOLT FIXITY, SUCH THAT $l = .75$ IN (CONSERVATIVE)

$M_{MAX} = .75 \times 3170 = 2380$ IN #

$I/y = \frac{1.5(t)^2}{6} = .25t^2$

LET $F_{ty} = 130{,}000 \cdot 1.22 = 160{,}000$ psi @ 300°F

$160{,}000 = \frac{2380}{.25t^2}$

$t^2 = \frac{2380}{.25 \times 160{,}000} = .0595$

$t = .244$ MIN HT. TO 160 KSI

IF $F_{ty} = 75{,}000 \times 1.22 = 90{,}000$ psi FOR NORM.

$t = \left(\frac{2380}{.25 \times 90{,}000}\right)^{\frac{1}{2}} = .326$ MIN NORM.

FOR .500 t $\quad M.S. = \left(\frac{.500}{.244}\right)^2 - 1 = \text{LARGE}$

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13. ABSTRACT

Under a joint program between the 6585 Test Group/TK and the Ramjet and Laser Aerodynamics Division of the Aero Propulsion Laboratory, an existing monorail test sled was modified to accept the SCP/LASRM test vehicle. The necessary structural modifications were made to the SCP/LASRM hardware to withstand the applied loads imposed by the sled.

The feasibility of ramjet engine test capability on the Holloman Sled Track was confirmed by comparison of ramjet performance data obtained during high speed sled tests to that available from previous ground freejet and flight tests with this engine. Propulsion performance data over the Mach range 2.3 to 2.5 at zero degree angle of attack were obtained from the sled tests.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Sled Track						
Monorail Sled						